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CALCULATION OF COST IN DESIGN OF MACHINERY

By

M. I. IPATOV

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CONTENTS	PAGE
INTRODUCTION.....	1
CHAPTER 1: Calculating Production Cost During Preproduction Designing.....	13
CHAPTER 2: Production Cost Calculations During Preproduction Engineering.....	84
CHAPTER 3: Economically Allowable (Maximum) Production Cost and Machinery Price.....	111
APPENDICES.....	132
SYMBOLS APPEARING IN TEXT.....	162
BIBLIOGRAPHY.....	165

## INTRODUCTION

In order to estimate the technical-economic effectiveness of a piece of machinery on the drawing board, we need a comprehensive analysis of its economy in the area of production, performed by means of comparison of the cost of production and wholesale-release price of this machine with the cost of production and wholesale-release price of the most modern equipment of similar function. We also need an analysis of the economy of comparable machinery in operation, performed by comparing their productivity and operating-maintenance costs. One analysis element is determination of the allowable (maximum) cost and maximum machinery price, and their comparison with calculated figures obtained on analogous indices.

Figure 1 contains the sequence of technical-economic analysis of a newly-designed piece of equipment in consolidated form.<sup>1</sup>

It is expedient to represent the job of analyzing the effectiveness of the newly-designed piece of machinery (unit, assembly, part) in the form of a critical-path model, since such a model makes it easy to trace by event numbers both the sequence of task execution and all their interlinks.

Figure 2 contains a detailed diagram, in the form of a critical-path model, of the sequence of technical-economic analysis of machinery design, while Table 1 lists the events and tasks contained in the analysis.<sup>2</sup> For example, calculation of annual depreciation allowance (operation 16, 18) cannot be performed until the machinery wholesale-release price is calculated (operation 15, 16), as well as productivity (task 0, 4 and function 4, 18) for many kinds of machinery, such as transport equipment.

The form of the model depicted in Figure 2 may change somewhat in different calculations. For example, relation 16,19 will prove unnecessary if calculations of annual expenditures on operation and maintenance are performed not by utilizing a specific standard percentage of the wholesale-release price of the machinery. The critical-path model fragment from 0 to the 15th event can be presented in the form of a single operation if machinery production cost calculations are performed on the basis of utilization of its specific relationship with the specifications and production parameters

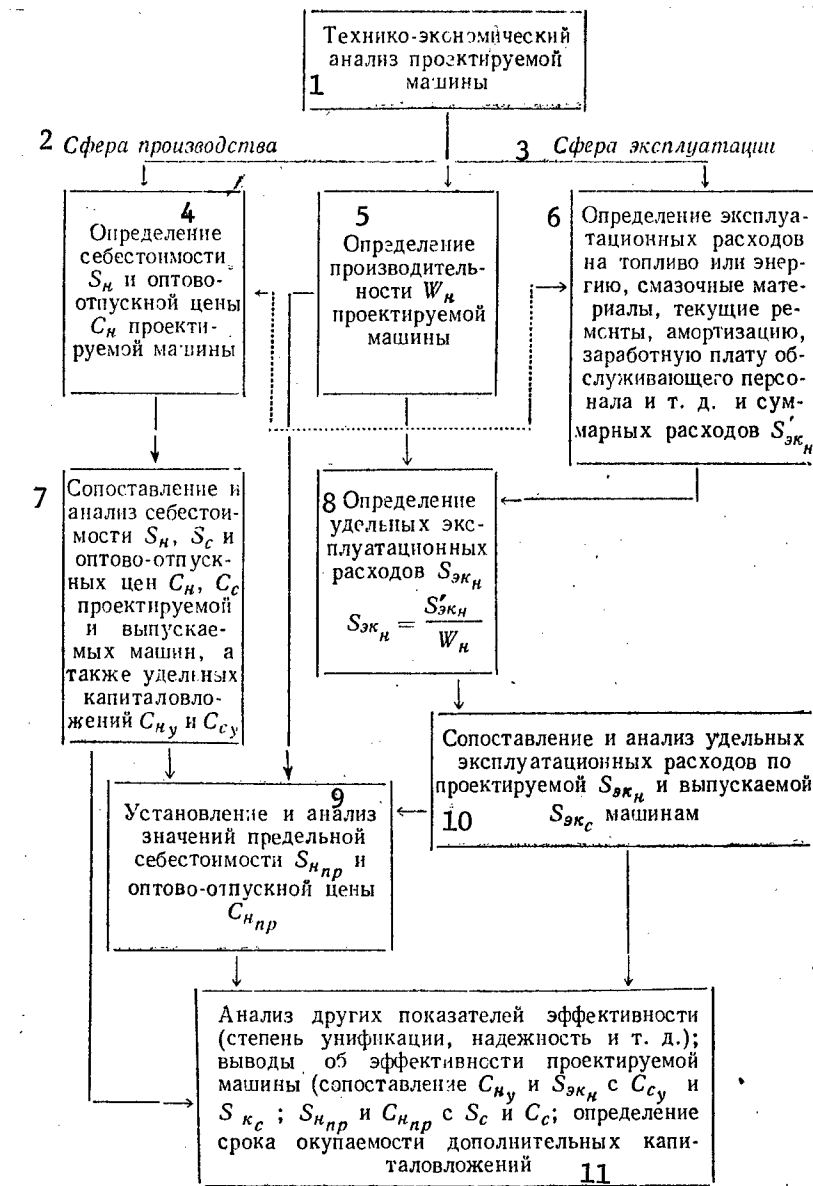


Figure 1. Block Diagram of Technical-Economic Analysis of a Newly-Designed Piece of Equipment (the Dotted Line Indicates the Relationship Between Size of Depreciation Allowance and Wholesale-Release Price)

Key to figure: 1 -- technical-economic analysis of designed equipment; 2 -- production sphere; 3 -- operation and maintenance sphere; 4 -- determination of cost  $S_n$  and wholesale-release price  $C_n$  of newly-designed equipment; 5 -- determination of productivity  $W_n$  of newly-designed equipment; 6 -- determination of operating expenditures for fuel or power, lubricants, minor repairs, depreciation, operating personnel wages, etc, and total expenditures  $S'_{ek_n}$ ; 7 -- comparison and analysis of cost  $S_n$ ,  $S_o$  and wholesale-release prices  $C_n$

(Key to Figure 1, cont'd)  $C_n$ ,  $C_o$  of newly-designed and currently-produced equipment, as well as specific capital investment  $C_{ny}$  and  $C_{oy}$ ; 8 -- determination of specific operating and maintenance costs; 9 -- determination and analysis of values: maximum cost... and wholesale-release price; 10 -- comparison and analysis of specific operating-maintenance costs for newly-designed... and currently-produced... equipment; 11 -- analysis of other effectiveness indices (degree of standardization, reliability, etc); conclusions on effectiveness of newly-designed equipment (comparison of .....; determination of time to recovery of additional capital investment

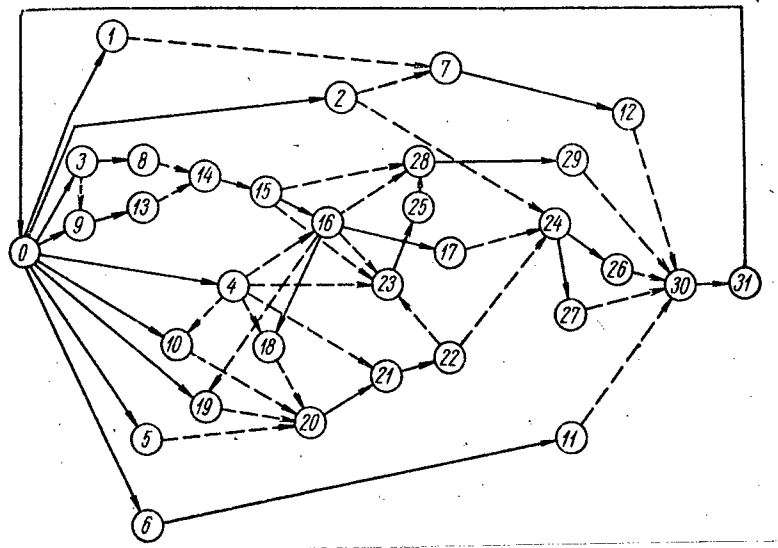


Figure 2. Critical-Path Model of Technical-Economic Analysis of a Newly-Designed Piece of Equipment

of the machinery. Operations 24, 26 are eliminated if specific capital investment and specific operating and maintenance expenditures on the newly-designed item are less than on analogous items selected as objects for comparative analysis, etc. However, these partial changes in the critical-path model do not disturb its basic structure.

In performing specific calculations on complex items, the model can be utilized as a primary critical-path model for the individual in charge. In this case the person in charge calculates critical-path model parameters, with the aid of determinant or probability time estimates, determines the critical path, time reserves, etc, that is, performs normal critical-path method system procedures.

Table 1. List of Events and Operations of Critical-Path Model of Technical-Economic Analysis of Newly-Designed Item

а Код собы- тия	б Событие	с Код работы	д Работа
0	Исходные конструктивные, производственные и эксплуатационные данные по проектируемому изделию (известные на данном этапе подготовки производства) получены	0,1	Определение унификационных показателей (коэффициентов стандартизации, преемственности и др.)
		0,2	Выбор сопоставимых машин для сравнительного анализа
		0,3	Определение чистого и черного весов, расхода материалов, комплектующей продукции
		0,9	Расчеты трудоемкости изготовления изделия
		0,4	Расчеты производительности изделия (или другие аналогичные расчеты)
		0,10	Определение годовых эксплуатационных расходов на горюче-смазочные материалы и энергию
		0,19	Определение годовых расходов на эксплуатационные ремонты
		0,5	Определение годовых расходов на заработную плату обслуживающего персонала и прочих расходов
		0,6	Выбор современных зарубежных аналогичных изделий для сравнения
1	Унификационные показатели определены	1,7	Зависимость (фиктивная работа)
2	Сопоставимые машины для сравнительного анализа выбраны	2,7	Зависимость
		2,24	»
3	Расход материалов определен, перечень комплектующей продукции установлен	3,8	Расчет затрат на материалы и комплектующую продукцию

Table 1 (cont'd)

а Код Сод. тип	б Событие	с Код работы	д Работа
4	Производительность изделия (или другой аналогичный показатель) установлена	3,9 4,10 4,16 4,18 4,21 4,23	Зависимость » » » » »
5	Годовые расходы на заработную плату обслуживающего персонала и прочие расходы определены	5,20	Зависимость
6	Современные зарубежные аналогичные изделия для сравнительного анализа выбраны	6,11	Сравнение проектируемого и зарубежных изделий по конструктивным, эксплуатационным, удельным и прочим показателям
7	Унификационные показатели по проектируемому и сопоставимым изделиям имеются	7,12	Сравнительный анализ унификационных показателей по проектируемому и сопоставимым изделиям
8	Затраты на материалы и комплектующую продукцию получены	8,14	Зависимость
9	Трудоемкость изготовления изделия определена	9,13	Расчеты заработной платы основных производственных рабочих
10	Годовые эксплуатационные расходы на горюче-смазочные материалы и энергию определены	10,20	Зависимость
11	Сравнение изделия с зарубежными образцами проведено	11,30	»
12	Сравнительный анализ унификационных показателей по проектируемому и сопоставимым изделиям проведен	12,30	»
13	Заработная плата основных производственных рабочих определена	13,14	»
14	Данные о затратах на материалы, комплектующую продукцию, заработную плату и косвенные расходы имеются	14,15	Расчет себестоимости проектируемого изделия

Table 1 (cont'd)

а Код собы- тия	б Событие	с Код работы	д Работа
15	Себестоимость проектируе- мого изделия определена	15,16	Расчет оптово-отпуск- ной цены проектируемого изделия
		15,23	Зависимость
		15,28	»
16	Оптово-отпускная цена проектируемого изделия опре- делена	16,17	Расчет удельных капи- тальных вложений у по- требителя
		16,18	Расчет годовых аморти- зационных отчислений
		16,19	Зависимость
		16,23	»
		16,28	»
17	Удельные капитальные вло- жения у потребителя опреде- лены	17,24	»
18	Годовые амортизационные отчисления определены	18,20	»
19	Годовые расходы на эксплу- атационные ремонты опреде- лены	19,20	»
20	Все статьи годовых эк- сплуатационных расходов рассчитаны	20,21	Определение суммарных годовых эксплуатацион- ных расходов
21	Суммарные годовые эксплу- атационные расходы опреде- лены	21,22	Расчет удельных эк- сплуатационных расходов
		22,23	Зависимость
22	Удельные эксплуатацион- ные расходы определены	22,24	»
23	Все данные для расчета предельной себестоимости и предельной оптово-отпускной цены имеются	23,25	Расчеты предельной себестоимости и предель- ной оптово-отпускной це- ны проектируемого изде- лия
24	Все данные для расчета срока окупаемости дополни- тельных капитальных вложе- ний у потребителя и годового экономического эффекта имеются	24,26	Расчет срока окупае- мости дополнительных ка- питальных вложений
		24,27	Расчет годового эконо- мического эффекта
25	Предельная себестоимость и предельная оптово-отпускная цена рассчитаны	25,28	Зависимость
26	Срок окупаемости опреде- лен	26,30	»

Table 1 (cont'd)

а Код собы- тия	б Событие	с Код работы	д Работа
27	Годовой экономический эф- фект определен	27,30	Зависимость
28	Данные для сопоставления рассчитанных себестоимости и оптово-отпускной цены и их предельных значений имеются	28,29	Анализ полученных дан- ных о расчетных и пре- дельных значениях себе- стоимости и оптово-от- пускной цены
29	Анализ расчетных и пре- дельных значений себестоимос- ти и оптово-отпускной цены проведен	29,30	Зависимость
30	Все данные для выводов о техничко-экономической эффек- тивности проектируемого из- делия имеются	30,31	Выводы о технико-эко- номической эффективности проектируемого изделия
31	Выводы о технико-эконо- мической эффективности проек- тируемого изделия сделаны	31,0	Принятие решений о выполнении дальнейших этапов проектирования или о необходимости доработ- ки конструкции на дан- ном этапе или о прекра- щении дальнейших работ по данному изделию

Key to table: a -- event code; b -- event; c -- operation code; d -- operation; 0 -- design, production and operation-maintenance input data on newly-designed item (known at the given stage of preproduction) have been obtained; 1 -- standardized indices determined; 2 -- comparable items for comparative analysis selected; 3 -- materials requirements determined, list of component items established; 4 -- item productivity (or other analogous indicator) established; 5 -- annual outlays on operator personnel wages and expenditures determined; 6 -- similar modern foreign items for comparative analysis selected; 7 -- standard indices on newly-designed and comparable items available; 8 -- outlays on materials and component items obtained; 9 -- labor requirements of item manufacture determined; 10 -- annual operating costs for fuels, lubricants and electric power determined; 11 -- comparison of item with foreign models performed; 12 -- comparative analysis of standardization indices on new-design and compared items performed; 13 -- wages of basic production workers determined; 14 -- figures on outlays for materials, component items, wages and indirect expenditures available; 15 -- production cost of newly-designed item determined; 16 -- wholesale-release price of newly-designed item determined; 17 -- specific capital investment by purchaser determined; 18 -- annual depreciation allowance determined; 19 -- annual operating and maintenance costs determined; 20 -- all items of annual operating and maintenance costs calculated; 21 -- total annual operating and maintenance costs determined; 22 -- specific operating and maintenance costs determined; 23 -- all figures available for calculation of maximum production cost and maximum wholesale-release price; 24 -- all figures

available for calculating time to recovery of purchaser's additional capital investment and annual savings; 25 -- maximum production cost and maximum wholesale-release price calculated; 26 -- time to recovery of investment determined; 27 -- annual savings determined; 28 -- figures available for comparison of calculated production cost and wholesale-release price and their maximum values; 29 -- analysis of calculated and maximum production cost and wholesale-release price performed; 30 -- all data available for conclusions on technical-economic effectiveness of newly-designed item; 31 -- conclusions reached on technical-economic effectiveness of newly-designed item; 0,1 -- determination of standardization indices (standardization factor, succession coefficient, etc); 0,2 -- selection of comparable machinery for comparative analysis; 0,3 -- determination of net and rough weights, consumption of materials and component items; 0,9 -- calculations of item manufacture labor requirements; 0,4 -- calculation of item productivity (or other analogous calculations); 0,10 -- determination of annual operating expenses for fuels, lubricants and electricity; 0,19 -- determination of annual expenditures on maintenance; 0,5 -- determination of annual expenditures on operating personnel wages and other outlays; 0,6 -- selection of similar modern foreign-made items for comparison; 1,7 -- relation (fictitious operation); 2,7 -- relation; 3,8 -- calculation of expenditures on materials and component items; 3,9 -- relation; 5,20 -- relation; 6,11 -- comparison of newly-designed and foreign items on the basis of design, operation, specific and other indices; 7,12 -- comparative analysis of standardization indices of new-design and compared items; 8,14 -- relation; 9,13 -- calculation of wages of basic production workers; 10,20 -- relation; 14,15 -- calculation of production cost of newly-designed item; 15,16 -- calculation of wholesale-release price of newly-designed item; 15,23 -- relation; 16,17 -- calculation of purchaser's specific capital investment; 16,18 -- calculation of annual depreciation allowance; 16,19 -- relation; 20,21 -- determination of total annual operating and maintenance costs; 21,22 -- calculation of specific operating and maintenance costs; 22,23 -- relation; 23,25 -- calculations of maximum production cost and maximum wholesale-release price of newly-designed items; 24,26 -- calculation of time to recovery of additional capital investment; 24,27 -- calculation of annual savings; 25,28 -- relation; 27,30 -- relation; 28,29 -- analysis of obtained data on calculated and maximum production cost and wholesale-release price; 29,30 -- relation; 30,31 -- conclusions on technical-economic effectiveness of newly-designed item; 31,0 -- decision-making on subsequent stages of the designing process or on the necessity of finishing the design at the present stage or termination of work on the given item

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Also shown in the critical-path model in Figure 2 is feedback (procedure 31,0) -- optimization of design, as a result of which a closed loop is formed, which fundamentally distinguishes this model from conventional models.

At each stage in the design process, following technical-economic analysis by the designers, one of the following decisions, determined by analysis results, should be made: the design is a good one, and we can proceed to

the next design stage; the design requires additional work at the present stage in order to improve effectiveness indices; the design is not effective, and further work on it must be terminated, or the given input parameters must be substantially changed. The technical-economic analysis is practically useless without this feedback.

Determination of machinery production cost is an important item in performing an analysis. Calculated production cost is used both to determine the wholesale-release price on the newly-designed item (production sphere) and for calculating depreciation allowance (operation sphere -- see dashed arrow in Figure 1 and operation 16,18 in Figure 2). We should note that the depreciation allowance in the operation of some pieces of complex machinery manufactured in small numbers comprises a substantial part of operating expenses. Tables 2 and 3 present the approximate structure of operating cost of modern Soviet mass-produced and small-series bulldozers as well as mass-production trucks.

1 Статьи затрат	2 Бульдозеры	
	3 массового производ- ства	4 мелкосе- рийного произ- водства
5 Единовременные затраты (связанные с пере- броской на другую площадку) . . . . .	3	1
6 Амортизационные отчисления . . . . .	35	66
7 Сменные затраты (на заработную плату об- служивающего персонала, на топливо) . . . . .	45	20
8 Прочие сменные затраты [на ремонтные рабо- ты (кроме капитального), на смазочные мате- риалы] . . . . .	17	13
9 Всего . . .	100	100

Table 2. Structure of Vehicle-Shift Cost for Bulldozers, %

Key to table: 1 -- expenditure items; 2 -- bulldozers; 3 -- mass production; 4 -- small-series production; 5 -- one-time outlays (connected with transfer to another site); 6 -- depreciation allowance; 7 -- shift expenditures (for operating personnel wages, fuel); 8 -- other shift expenditures [maintenance and repairs (other than major overhaul), lubricants]; 9 -- total

As is evident from the tables, the percentage share of depreciation allowance in cost of vehicle operation changes substantially, in relation to the wholesale-release price, which in turn is determined by the scale of manufacture. For mass-produced vehicles the depreciation allowance is usually more than 10%; with series, small-series and custom manufacture the depreciation allowance can be as high as 60-80%. Thus an error made in calculating machinery production cost may reflect negatively in calculations of operating costs and in calculations of machinery technical-economic effectiveness as a whole.

Table 3. Average Structure of Annual Operating Expenses for Trucks, %

1 Статьи затрат	2 Грузовые автомобили	
	3 с карбюраторными двигателями	4 с дизельными двигателями
5 Топливо . . . . .	14	7
6 Смазочные и обтирочные материалы . . . . .	2	2
7 Техническое обслуживание и эксплуатационные ремонты . . . . .	14	19
8 Амортизационные отчисления . . . . .	10	21
9 Восстановление износа и ремонт шин . . . . .	6	9
10 Заработная плата водителя . . . . .	30	22
11 Обслуживание в автопарках . . . . .	24	20
12 Всего . . . . .	100	100

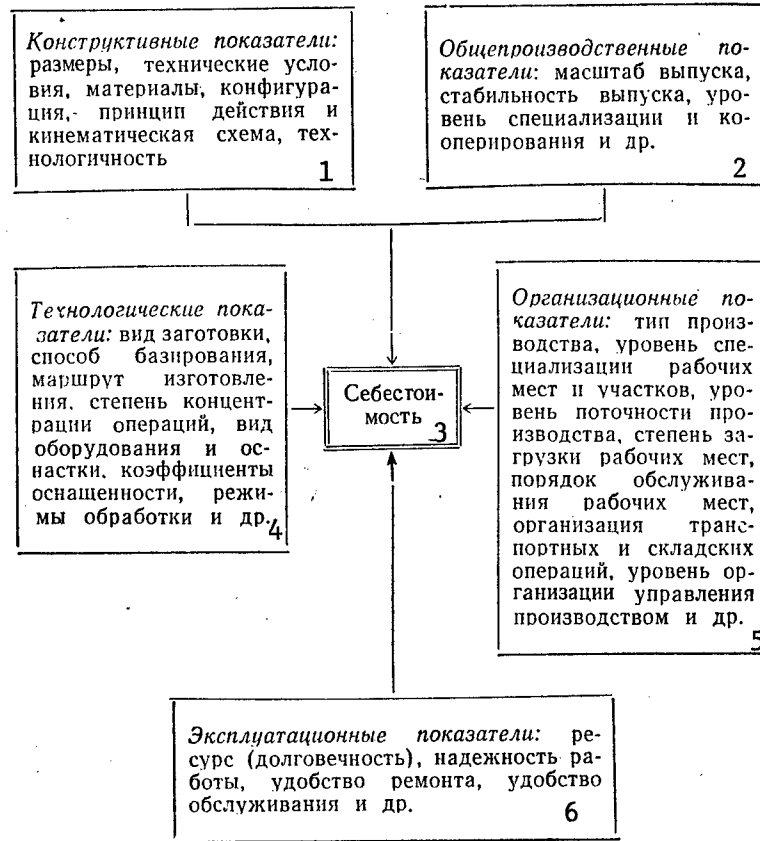
Key to table: 1 -- expenditure items; 2 -- trucks; 3 -- with carburetor-type engines; 4 -- with diesel engines; 5 -- fuel; 6 -- lubricants; 7 -- servicing and maintenance; 8 -- depreciation allowance; 9 -- tire depreciation and repairs; 10 -- driver wages; 11 -- garage services; 12 -- total

Machinery production cost is influenced by many indices: design, production, technological, organization, and operational (Figure 3). In practical terms it is very difficult to take the great diversity of indices into account even with the availability of full support data on the item (machine) being manufactured. This data makes it possible to determine the planned production cost of a piece of machinery and to establish a wholesale-release price taking into consideration specific production profitability. One can precisely determine, however, whether a wholesale-release price has been correctly established only as a result of thorough calculations of operating indices, which makes it possible to introduce a correction taking into account savings achieved by the purchaser of the item.

Due to the lack of manufacturing process data it is impossible to determine time requirements, the precise weight and materials requirements, since detailed drawings are prepared only at the final stage of design (the working drawings stage), while process drawings (of required castings and forgings, for example) are not prepared until the process of preparation for production. Normal costing methods specified by the instructions of the USSR Gosplan and the USSR Ministry of Finance [8], require preliminary determination of materials requirements on the basis of drawings (and manufacturing processes) and labor requirements based on standard time requirements.

Therefore in the process of designer preproduction activities it is necessary to employ special methods of calculating production cost which will make it possible to utilize the data which are known at this stage. These

Figure 3. Diagram of Influence of Basic Indices on Machinery Production Cost



Key to figure: 1 -- design indices: dimensions, specifications, materials, configuration, principle of operation and kinematic diagram, technological feasibility; 2 -- general production indices: scale of production, stability of production, level of specialization and cooperative manufacture, etc; 3 -- production cost; 4 -- manufacturing process indices: type of blank or workpiece, method of basing, production routing, degree of concentration of operations, type of equipment, equipment factors, processing conditions, etc; 5 -- organizational indices: type of production, level of specialization of work stations and sections, level of production flow, degree of work station work-loading, procedure and sequence of work station servicing, organization of transfer and warehouse operations, level of organization of production management, etc; 6 -- operating indices: service life, operational reliability, ease of maintenance and repair, ease of operation and servicing, etc.

calculations, initially consolidated, should subsequently be refined, as more information is acquired. At the production process setup stage, when figures on labor and materials requirements appear, they can be brought to the accuracy of plan calculations. Even at early stages of preparation, however, it is essential to employ production cost calculation methods which will make it possible to ensure departure of not more than  $\pm 10-15\%$  from actual production cost.

In connection with this it is necessary to elaborate and apply methods of production cost calculation which provide designers with objective and reliable material for judging the influence of given design changes on production cost and for determining those parameters of machinery being designed which exert the greatest influence on production cost. It is essential for designers to possess a reliable tool with the aid of which they can know in advance what parameters of a machine or its components require thorough analysis and appropriate technical-economic calculations. In other words, it is necessary to calculate production cost with methods with the aid of which it would be possible to establish not only a direct relationship between a machine's parameters and production cost but also feedback, making it possible to optimize the design, not on the basis of intuition but based on objective criteria.

#### FOOTNOTES

1. The symbols employed in the text are listed at the back of the book.
2. For critical-path methods in planning and management see Belova, L. D., et al: "Setevoye planirovaniye i upravleniye" [Critical-Path Method], Moscow, Znaniye, 1966; Razumov, I. M., et al: "Setevyye grafiki v planirovanii" [Network Charts in Planning], Moscow, Vysshaya shkola, 1967.

## CHAPTER 1.

### CALCULATING PRODUCTION COST DURING PREPRODUCTION DESIGNING

#### 1. Machine Parameters and Production Cost

In preproduction designing the method of analogy may be the most acceptable method of approximate calculation of machinery production cost. This method is essentially the following: the production cost of a machine being designed is calculated on the basis of analysis of specific parameters of the machine or its components known at the given stage.

Utilized for the calculation are standard reference or statistical materials on quantitative correlations between these parameters and the production cost of machinery of similar function which is currently in production. These statistical materials, however, should be suitably prepared and processed for calculations of production cost of machinery being designed.

Machinery production cost is influenced by its specifications and performance parameters, as well as organizational and production indices (see Figure 3). In production cost calculations it is impossible at the design stage to figure in the entire complex of technical, operational, organizational and production parameters. For an approximate estimate of production cost, allowing for error which does not distort on the whole the results of calculations of technical-economic effectiveness, it is sufficient to limit oneself to an expedient minimum number of parameters which influence production cost to the greatest degree. This can be done by applying mathematical-economic simulation methods, that is, by selecting those parameters which exert the greatest influence on the target parameter, in this instance production cost.

The selected parameters are designated by mathematical symbols, and their relations are written down in the form of mathematical expressions.

Principal stages of the preproduction design process include the preliminary design, design sketches, technical and working design; another component

part of preproduction design is the building and testing of experimental models if a given item is to go into series or mass production.

As a rule several basic parameters which influence production cost can be specified at each stage of preproduction design. Table 1.1 contains several methods of determining production cost at various stages of preproduction designing, by utilization of known correlations between machine parameters and production cost.

Up to the present time the economics literature has frequently recommended that one examine production cost on the basis of some one specific indicator (cost per ton of weight, cost per unit of load capacity or per unit of output, etc). There is lacking thereby sufficiently substantiated recommendations on utilization of a given indicator, while the results of calculations frequently prove to be quite far from a realistic production cost indicator obtained on the basis of documents elaborated in the process of preproduction engineering.

In all these calculations it is assumed as a rule that outlays change directly proportional to change in one determining parameter (weight, for example). For example, if the specific production cost of a machine is equal to 0.5 rub/kg, then in designing a new and similar machine weighing 100 kg less, the calculated production cost will be 50 rubles less.

However, such a calculation fails to take into consideration the possible increased complexity of the new design as well as a different specific cost of its elements (see Table 1.2). Employment of an averaged specific indicator in complex machinery can lead to serious errors in calculating production cost.

As is evident from Table 1.3, the average specific cost of producing tractors ranges between 0.3 and 0.5 rub/kg. However, if we utilize these averaged figures for calculating the cost of producing the running gear of a new tractor, a substantial error will arise, since the specific cost of producing the running gear of caterpillar tractors is approximately 0.1-0.15 rub/kg, that is, 2 to 5 times less than the average, while for wheel-type tractors it is approximately 0.65-0.8 rub/kg, that is, 1.5-2 times higher than the average tractor cost.

Therefore consolidated specific indicators can be permitted only for branches which are engaged in single-item production, where it is difficult to establish more reliable relations. For branches with series and mass production, such indicators are allowable only as an exception, at the earliest stages of preproduction design, in preparing or refining the preliminary design and in the absence of any standard or statistical data on items of a similar nature and function which are currently in production.

Table 1.1. Methods of Determining Production Cost at Different Stages of Preproduction Designing

1 Этап	2 Состав основных работ	3 Примерный перечень известных параметров на данном этапе, влияющих на себестоимость	4 Возможные методы расчета себестоимости
5 Разработка технического задания	Разработка характеристик новой машины и областей применения; определение конструктивных особенностей и основных параметров машины; обоснование необходимости изготовления машины и ее модификации; технико-экономический расчет эффективности; согласование задания с потребителями и утверждение его 9	10 Вес изделия; мощность; рабочие скорости; техническая производительность; габариты; ресурс; срок службы; масштаб выпуска и др.	11 Укрупненные методы расчета себестоимости, например: по удельному показателю; по методу баллов; путем корреляционного анализа конструкторских, эксплуатационных и производственных параметров, влияющих на себестоимость, и др.
6 Разработка эскизного проекта	Разработка кинематических, гидравлических и других схем машины 12  Разработка эскизных чертежей общих видов 13  Составление спецификаций узлов и механизмов; выявление	Вес изделия; мощность; рабочие скорости; техническая производительность; габариты; ресурс, срок службы; масштаб выпуска и др. 16  Мощности, крутящие моменты, скорости и т. д. в отдельных агрегатах и узлах машины Масштабы выпуска агрегатов, механизмов и узлов с учетом	17 Методы поагрегатного или узлового расчета себестоимости, например: путем определения затрат на материалы, полуфабрикаты и покупные изделия (М); использования данных о доле М в себестоимости; учета коэффициента серийности и суммирования полученных результатов по всем изготавливаемым агрегатам и узлам со стоимостью покупных агрегатов и
	унифицированных и покупных узлов и механизмов машины; технико-экономические расчеты эффективности принимаемых решений 14	унификации. Покупные агрегаты, механизмы и узлы 16	узлов; путем корреляционного анализа основных параметров, влияющих на себестоимость проектируемых агрегатов и узлов и суммирования полученных результатов по всем проектируемым агрегатам и узлам со стоимостью покупных агрегатов и узлов и др.
7 Разработка технического проекта	Компоновка машины; разработка чертежей общих видов агрегатов и узлов; уточнение спецификаций покупных изделий; расчеты на прочность, долговечность, жесткость, точность; составление спецификаций материалов; составление технических условий; технико-экономические расчеты эффективности принимаемых решений 18	Те же, что для этапов разработки технического задания и разработки эскизного проекта 19	
Разработка рабочего проекта	Разработка рабочих чертежей; составление принципиальной схемы сборки изделия; изготовление и испытание опытных образцов; корректировка рабочих чертежей; составление технических условий на материалы; составление подетальных и материальных спецификаций. Уточненный технико-экономический анализ эффективности конструкций 20	Все, что было для этапов разработки технического задания, разработки эскизного проекта, разработки технического проекта. Фактический вес агрегатов и узлов. Материал деталей. Число обрабатываемых поверхностей; характер заготовки 21	Уточнение проведенных ранее расчетов по сложным агрегатам и узлам на основе установления подетальных зависимостей себестоимости (или материалоемкости и трудоемкости) от конструктивных, эксплуатационных и производственных параметров, с использованием разработанной технической документации (чертежи, спецификации и т. п.) 22

Key to Table 1.1 on preceding page: 1 -- stage; 2 -- composition of principal operations; 3 -- approximate list of known parameters at the given stage which influence production cost; 4 -- possible methods of calculating production cost; 5 -- preliminary design; 6 -- preliminary drawings; 7 -- preliminary engineering; 8 -- detailed engineering; 9 -- elaboration of general specifications of the new machinery and areas of application; determination of design features and principal machine parameters; substantiation of the need to manufacture the machine and its modification; technical-economic calculation of effectiveness; customer approval of preliminary design and its ratification; 10 -- weight of item; power; operating speeds; productivity; size; durability, service life; scale of production, etc; 11 -- consolidated methods of calculating production cost, for example: on the basis of specific indicator; by the point method; by means of correlation analysis of design, operating and production parameters influencing production cost, etc; 12 -- preparation of kinematic, hydraulic and other machinery diagrams; 13 -- preparation of general sketches; 14 -- preparation of specifications of assemblies and mechanisms; determination of standardized and purchased machine assemblies and mechanisms; technical-economic calculations of the effectiveness of decisions reached; 15 -- figures on power, torque, speeds, etc in individual units and assemblies; 16 -- scale of production of units, mechanisms and assemblies, taking standardization into account. Purchased units, mechanisms and assemblies; 17 -- methods of calculation of production cost on a unit-by-unit or assembly-by-assembly basis, for example: by determining outlays on raw materials, semifinished products and purchased items (M); utilization of figures on the percentage share of M in production cost; figuring the coefficient of series production and adding up the obtained results on all units and assemblies produced, with the cost of purchased units and assemblies; by means of correlation analysis of the principal parameters influencing the cost of designed units and assemblies and adding up the obtained results for all designed units and assemblies with the cost of purchased units and assemblies, etc; 18 -- machine layout; preparation of general drawings of units and assemblies; refinement of specifications of purchased items; strength, durability, rigidity and precision calculations; preparation of materials specifications; preparation of general specifications; technical-economic calculations of effectiveness of solutions reached; 19 -- same as for preliminary design and preliminary drawings stage; 20 -- preparation of working drawings; preparation of basic assembly diagram; fabrication and testing of experimental models; correcting of working drawings; preparation of specifications on materials; preparation of detailed specifications on parts and materials. Refined technical-economic analysis of design effectiveness; 21 -- same as for preliminary design, preliminary drawings, and preliminary engineering stages. Actual weight of units and assemblies. Parts materials. Number of machined surfaces; character of machine blanks and workpieces; 22 -- refinement of previous calculations on complex units and assemblies on the basis of establishment of part-by-part relationships between production cost (or materials and labor requirements) and design, operation and production parameters, with utilization of prepared engineering data (drawings, specifications, etc)

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Table 1.2. Specific Cost of Producing Trucks, at 100,000 Units Per Year

Автомобиль 1		Двигатель 2		Коробка передач 3		Задний мост 4		Рама 5	
Собственный вес в кг 6	Удельная себестоимость в руб/кг 7	Собственный вес в кг	Удельная себестоимость в руб/кг	Собственный вес в кг	Удельная себестоимость в руб/кг	Собственный вес в кг	Удельная себестоимость в руб/кг	Собственный вес в кг	Удельная себестоимость в руб/кг
1 500	0,34	150(к)	0,70	25	0,80	80	0,50	125	0,22
2 500	0,33	235(к)	0,68	45	0,70	250	0,30	215	0,17
4 000	0,30	400(к)	0,63	110	0,60	450	0,27	380	0,16
12 000	0,15	800(д)	0,56	220	0,55	880	0,23	540	0,13

Примечание: (к)—карбюраторный, (д)—дизельный.

Key to table: 1 -- truck; 2 -- engine; 3 -- transmission; 4 -- rear axle; 5 -- frame; 6 -- weight, kg; 7 -- specific cost in rubles per kg; note: (к) -- carburetor, (д) -- diesel

Table 1.3. Specific Production Cost, Tractors

1 Тракторы	2 Мощность в л. с.	3 Удельная себестоимость в руб/кг		
		4 трактора	5 трактора без ходовой части	6 ходовой части
7 Гусеничные дизельные . .	50—100	0,314	0,430	0,085
	30—50	0,358	0,440	0,147
8 Колесные дизельные . . .	20—35	0,500	0,435	0,800
	14—20	0,520	0,500	0,650
9 Колесные бензиновые . . .	12	0,500	0,455	0,650

Key to table: 1 -- tractors; 2 -- horsepower; 3 -- specific production cost in rubles per kg; 4 -- of tractor; 5 -- of tractor without running gear; 6 -- of running gear; 7 -- caterpillar diesels; 8 -- wheel diesel; 9 -- wheel gasoline

## 2. Methods of Calculating Production Cost at the Preliminary Design and Preliminary Drawings Stage

At the preliminary design and preliminary drawings stage one possesses incomplete and consolidated data on the new machine, particularly at the preliminary design stage (see Table 1.1). As a rule we know the weight of the item (sometimes a maximum figure which the designers must meet), required power, operating speeds (sometimes only maximum and minimum), maximum size, service life and requirements for coming years.

However, even with such a limited number of indicators, various methods of calculating production cost can be employed. We shall examine the following three methods, which are the most acceptable for calculating production cost at the preliminary design stage and during preparation of preliminary drawings: calculation on the basis of specific indicators, by the point method, and by the correlation method.

Calculation on the basis of specific indicators. The method of calculating production cost on the basis of specific indicators is the simplest and least precise method.

Calculation of the production cost of a new machine  $S_n$  with this method is performed with the following formulas:

$$S_n = S_{yG} G_n \text{ rub/unit} \quad (1.1)$$

$$S_n = S_{yN} N_n \text{ rub/unit} \quad (1.2)$$

where  $S_{yG}$  -- specific cost in rub/t;  $G_n$  -- calculated weight of machine in tons;  $S_{yN}$  -- specific cost in rub/kw (rub/hp);  $N_n$  -- motor output of designed machine in kw (hp).

Table 1.4 gives as an example standard values of specific indicators  $S_{yG}$  and  $S_{yN}$  for several metal-cutting machine tools and for press forging equipment [2]. Figure 1.1 shows change in the specific cost of models 1A62 and 1K62 universal lathes in relation to their weight [12], while Figure 1.2 shows change in the specific cost of producing trucks in relation to their load capacity. Such specific values can be obtained for all machinery in production.

1	Оборудование	2 $S_G$ в тыс. руб/т	3 $S_N$ в тыс. руб/квт
4	Револьверные станки с диаметром прутка в мм:		
	До 20 . . . . .	0,85—2,5*	0,23—0,95
	20—36 . . . . .	0,85—1,1	0,27—0,54
	36—63 . . . . .	0,65—0,85	0,32—0,55
	Свыше 63 . . . . .	0,57—1,0	0,15—0,65
5	Фрезерные горизонтальные станки . . . . .	0,6—0,7	0,23—0,3
6	Зубообрабатывающие станки:		
7	фрезерные . . . . .	0,55—0,9	0,7—0,9
8	долбежные . . . . .	0,9—2,55	1,45—4,25
9	Сверлильные вертикальные станки . . . . .	0,5—0,75	0,15—0,3
10	Шлифовальные станки:		
11	круглые . . . . .	0,4—0,6	0,25—0,3
12	плоские . . . . .	0,5—0,8	0,1—0,15
13	Механические прессы . . . . .	0,35—0,65	0,4—0,6
14	Молоты . . . . .	0,15—0,3	0,1—0,15
15	Горизонтально-ковочные машины . . . . .	0,65—0,85	1,1—1,3

\* Верхние пределы величин—для автоматов.

Table 1.4. Specific Cost Values  $S_G$  and  $S_N$  for Several Metal-Cutting Machine Tools and Press Forging Equipment

Key to Table 1.4 on preceding page: 1 -- equipment; 2 -- in thousand rub/t; 3 -- in thousand rub/kw; 4 -- turret lathes with rod diameter in mm; 5 -- horizontal milling machines; 6 -- gear-machining units; 7 -- gear-milling machines; 8 -- gear-shaping machines; 9 -- vertical drilling machines; 10 -- grinders; 11 -- cylindrical; 12 -- surface; 13 -- power presses; 14 -- hammers; 15 -- hot-forging machines; \* -- upper-limit figures are for automatic units

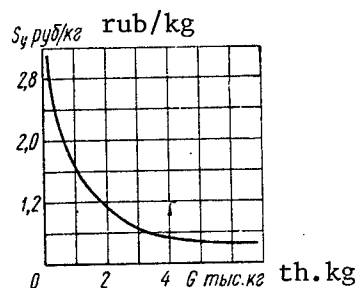


Figure 1.1. Relationship Between Specific Cost of Universal Lathes and Their Weight

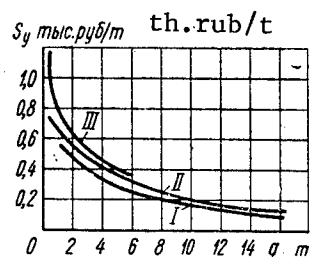


Figure 1.2. Relationship Between Specific Cost of Trucks and Their Load Capacity

Key to figure: I -- 4 x 2 and 6 x 4 trucks; II -- dump trucks; III -- 4 x 4 and 6 x 6 trucks

Calculations of this kind can be refined somewhat by employing differentiated specific indicators -- specific materials and labor requirements. In this case expenditures on materials, semimanufactures, purchased items  $M$  and on production worker basic wages  $L$  can be determined in a consolidated manner with the following formulas:

$$M = m_y G_n c_m \text{ rub/unit} \quad (1.3)$$

$$\dot{L} = t_{yd} G_n c_{m_c} \text{ rub/unit} \quad (1.4)$$

where  $m_y$  -- expenditure of materials, semimanufactures and purchased items in kg/kg (t/t);  $G_n$  -- calculated weight of machine in kg (t);  $c_m$  -- average cost of materials, semimanufactures and purchased items in rub/kg (rub/t);  $t_{yd}$  -- labor requirements per unit of machinery weight in norm hours per kg (norm hours per t);  $x_{m_c}$  -- average wage rate in rub/norm-hr.

Values  $m_y$  and  $t_{yd}$  are determined in advance for similar machines currently in production and are subsequently utilized for calculating M and L for the new machine. For example, for internal combustion engines, pumps, compressors, etc, we can employ for calculating L the following formula:

$$L = t_F F c_m \text{ rub/unit} \quad (1.5)$$

where  $t_F$  -- specific machining labor requirements in norm-hr/dm<sup>2</sup>; F -- cylinder machined surface in dm<sup>2</sup>;  $t_F$  can be obtained with the Ye. P. Kudryavtsev formula

$$t_F = \frac{T_{\text{обш}}}{F} = \frac{T_{\text{обш}}}{\pi D s n} \text{ rub/dm}^2 \quad (1.6)$$

where  $T_{\text{tot}}$  -- total labor requirements in norm-hours; D -- cylinder diameter in dm; s -- piston stroke in dm; n -- number of cylinders.

As experience shows, index  $t_F$  is fairly stable for internal combustion engines of various horsepower and output and can be successfully employed in production cost calculations.

Fairly frequently correlations [11] are employed in practice for geometricaly similar items:

$$T_{\text{обш}} \equiv G^{1/3}; \quad (1.7)$$

$$L = T_{\text{обш}} c_m \text{ rub/unit} \quad (1.8)$$

The labor requirements of a new machine can be obtained on the basis of known labor requirements of similar items with the formula

$$T_{\text{обш}_n} = T_{\text{обш}_c} \sqrt[3]{\frac{G_n^2}{G_c^2}} \text{ norm-hr/unit}, \quad (1.9)$$

where subscripts n and o designate the new and base machine respectively.

Lengipromash proposes a somewhat refined formula, which takes into account the differing character of interrelationship between basic and auxiliary time and item weight:

$$T_{\text{обш}_n} = T_{\text{обш}_c} \left( k_m \sqrt[3]{\frac{G_n^2}{G_c^2}} + k_b \sqrt[3]{\frac{G_n}{G_c}} \right) \text{ norm-hr/unit}, \quad (1.10)$$

where  $k_m$  and  $k_b$  -- percentage share of machine and auxiliary time in item labor requirements.

It is difficult in practice, however, to employ formula (1.10) at this stage of preproduction, due to the lack of requisite input data on machine and auxiliary time.

The above-described methods of calculating M and L make it possible to utilize the following formula to obtain production cost:

$$S_{y_n} = \left[ M + L \left( 1 + \frac{K_1 + K_2}{100} \right) + \right. \\ \left. + L \frac{\alpha}{100} \right] \left( 1 + \frac{K_3}{100} \right) \text{ rub/unit,} \quad (1.11)$$

where  $K_1$  -- indirect shop expenditures as a percentage of basic wages of production workers;  $K_2$  -- general plant indirect expenditures as a percentage of basic wages of production workers;  $K_3$  -- outlays additional to production costs, as a percentage of indirect costs (indirect costs -- quantity contained in square brackets); average value  $K_3=2-7$ ;  $\alpha$  -- percentage of supplementary wages and additional social insurance payments ( $\alpha=11-15\%$ ).

Quantities  $K_1$  and  $K_2$  are known for each enterprise and are fairly stable (if the adoption of a new piece of machinery does not require radical changes in production process and organization, such as production automation). We list below the average values of  $K_1$  and  $K_2$  for several branches of machine building, as percentages of basic wages of production workers.

Branch:	$K_1$	$K_2$
Agricultural Machine Building	250	100
Automotive and Tractor Machine Building	350	80
Transport Machine Building	300	180
Heavy Machine Building	200	80

Listed below are average  $K_1$  and  $K_2$  values as a percentage of basic wages of production workers at several machine building plants.

Plants:	$K_1$	$K_2$
Tractor	300	65
Carburetor	200	50
Turbine	400	100
Reduction Gear	225	80
Diesel	225	95
Excavator	240	80
Materials Handling Equipment	300	150

Thus the percentage of shop and general plant indirect expenditures is determined by the specific features of production at specific plants -- their manufacturing process and organizational features, which are

determined to a considerable degree by the scale of production and labor requirements of the products manufactured. Therefore quantities  $K_1$  and  $K_2$  in production cost calculations with formula (1.11) should correspond to the production conditions at specific plants.

Calculation by the point method. An approximate estimate of the cost of producing a new item at industrial plants can also be performed on the basis of the so-called point method. Essentially this method consists in the following: the principal design and operational characteristics of a new item of machinery -- size, speed, load capacity, etc -- are estimated with arbitrary points. The maximum point value for each parameter should be small, in the order of 2-3, and it is desirable to estimate this value in conformity with the degree of influence of each of the examined parameters on production cost. For many machines, for example, weight exerts the greatest influence on production cost, and therefore the maximum point value is taken as 3 for this parameter, and 2 for all other parameters. One should consider the type of machinery being estimated in selecting the maximum value of each parameter. For example, in place of a uniform system of points for all internal combustion engines of transport equipment, it is advisable to designate with a separate system of points, for example, motors up to 30 horsepower, with another category containing engines up to 100-150 hp, a third category -- up to 400 hp, a fourth -- up to 1,200 hp, proceeding in like manner in respect to other parameters. This will produce greater accuracy of computation results.

In each case the grouping should be based on distinctive features and characteristics of the corresponding machinery items and the adopted system of classification. As a rule the simplest -- linear -- form of relation is employed. This is entirely admissible, since processing of statistical materials and data on a new-design piece of machinery is conducted according to a uniform method. In plotting graphs one proceeds from the position that production cost, for example, can be considered directly proportional to engine horsepower, truck load capacity, category of machining precision, but is inversely proportional to the scale of production.

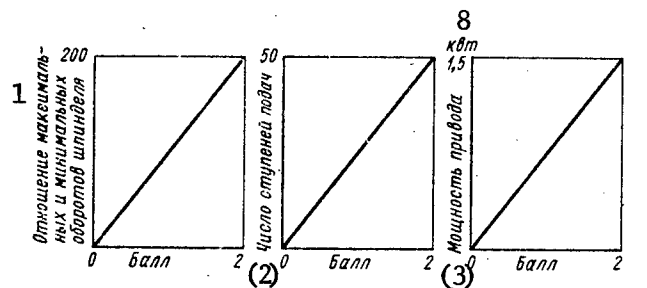


Figure 1.3 (cont'd on following page)

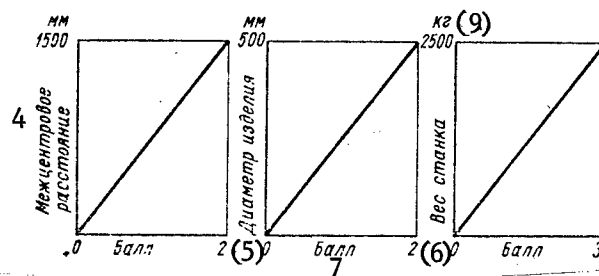


Figure 1.3. System of Points for Calculating Production Cost of Universal Screw-Cutting Lathes

Key to figure: 1 -- ratio of maximum to minimum spindle rpm; 2 -- number of feed rates; 3 -- drive horsepower; 4 -- distance between centers; 5 -- workpiece diameter; 6 -- weight of machine tool; 7 -- points; 8 -- kw; 9 -- kg

Figure 1.3 contains an example of a point system for calculating the production cost of universal screw-cutting lathes in the design process. Following are the principal parameters, known at an early stage of design: ratio of maximum to minimum spindle rpm; number of feed rates  $n_f$ ; power of main drive motor  $N_{dp}$  in kw; maximum distance between centers  $l$  in mm; maximum workpiece outside diameter  $d_{max}$  in mm; weight of machine tool  $G$  in kg.

The maximum point value for all parameters other than weight is 2, with 3 for weight, since we know from practical experience that the weight of a machine tool exerts greater influence on production cost than the other parameters.

The points obtained for each of the target parameters are added up. In order to estimate machinery production cost, the point total is multiplied by a value multiplier which is constant for each plant or branch. In order to determine its magnitude the actual production costs of similar machinery previously manufactured are divided by the corresponding total point values obtained for them. The mean arithmetic value of the obtained quantities is taken as the value multiplier for estimating new designs.

Table 1.5 contains an example of an analysis of point values and determination of a value multiplier for three Soviet-made engine lathes; the value multiplier has been determined for each of them, as well as the average value which can be utilized to calculate the production cost of the planned machine tools.

Figure 1.4 contains an example of a point system for calculating the production cost of a newly-designed truck with engine horsepower  $N_{db}=200$  hp, load capacity  $q=6$  t, top speed  $v_{max}=100$  km/h, and with eight wheels (including two spares), size 9.00-20.

$$\Sigma \text{ points} = 1.5 + 0.9 + 2 + 1.5 = 5.9.$$

Table 1.5. Calculation of Magnitude of Value Multiplier for Engine Lathes

1  Параметр	2 Станки					
	1Д62М		1А62		1К62	
	3 Абсолютное значение	4 Балл	Абсолютное значение	Балл	Абсолютное значение	Балл
Отношение числа оборотов шпинделя 5 . . . . .	52,2	0,52	104,4	1,04	160,0	1,60
Число ступеней подачи 6	35	1,45	35	1,45	42	1,70
Мощность электродвигателя главного привода в квт . 7 . . . . .	4,3	0,60	7,0	0,85	10,0	1,35
Максимальное межцентровое расстояние в мм 8 .	1500	2,00	1500	2,00	1400	1,90
Максимальный диаметр обработки изделия в мм 9 .	410	1,70	400	1,60	400	1,60
Вес станка в кг 10 . . .	1660	1,95	1900	2,25	2200	2,50
Себестоимость станка в руб. 11 . . . . .	747	—	855	—	1286	—
Суммарный балл 12 . .	—	8,22	—	9,19	—	10,65
Ценностной множитель в руб/балл . 13 . . . . .	747:8,22=91		855:9,19= =93,5		1286:10,65= =120	
Средний ценностной множитель в руб/балл 14 .	$\frac{91+93,5+120}{3} = 100$					

Key to table: 1 -- parameter; 2 -- lathes; 3 -- absolute value; 4 -- point value; 5 -- ratio of spindle rpm number; 6 -- number of feed rates; 7 -- power of main drive motor, in kw; 8 -- maximum distance between centers, mm; 9 -- maximum workpiece machining diameter, mm; 10 -- weight of machine tool, kg; 11 -- machine tool cost, rubles; 12 -- total point value; 13 -- value multiplier in rub/points; 14 -- average value multiplier in rub/points

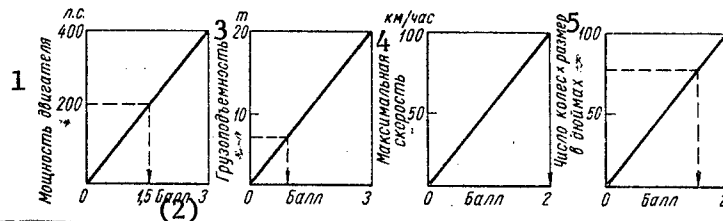


Figure 1.4. System of Points for Calculating the Production Cost of Trucks

Key to figure: 1 -- engine horsepower; 2 -- points; 3 -- load capacity; 4 -- top speed; 5 -- number of wheels times size in inches

If the average value multiplier for plants manufacturing trucks of a given type is 350 rub/points, then

$$S_n = 5.9 \times 350 = 2,065 \text{ rub/unit.}$$

On the whole this method provides satisfactory results for subsequent effectiveness calculations at the earliest preproduction stages. When it is utilized for production cost calculations, it is most important correctly to select technical and operating parameters. They should be small in number (not more than 4-6), and they should in fact exert the greatest influence on vehicle production cost.

The point method, with correct selection of input parameters, can provide more accurate calculation results than the method of calculation on the basis of specific indicators. In contrast to the latter, production cost here is an integral index. It takes into account the influence of several parameters, and therefore errors which may arise in calculating only on one or two parameters (method of calculating production cost on the basis of specific indicators) are leveled to a certain degree.

Warranted employment of the above method depends on amassing a sufficient quantity of statistical materials in order to obtain a value multiplier.

Calculation based on correlations. Establishment of the relationship between production cost, technical and operation parameters can also be effected with the aid of correlation analysis methods.

Since this method makes it possible to obtain the most accurate results in estimating production cost and is the most promising, we should examine it in greater detail.

Correlations are defined as relations whereby several values of one indicator may correspond to each value of another, but at the same time changes in one indicator produce logical changes in another.

A correlation or absence of a correlation is frequently established graphically, by plotting a so-called correlation field (Figures 1.5 and 1.6) [14].

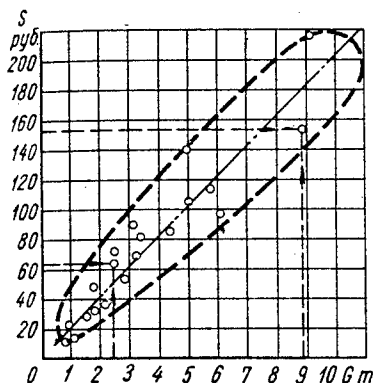


Figure 1.5. Relationship Between Truck Weight and Cost of Production (example of correlation field plotting)

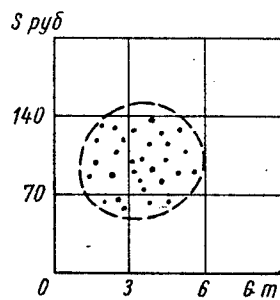


Figure 1.6. Relation Between Truck Weight and Production Cost (example of absence of correlation between two attributes)

Figure 1.5 shows the relationship between the weight of specific vehicles and the cost of producing them. Although the points which describe the relationship between these two parameters show a certain degree of dispersion, all are located along an axis (the dash-dot line), and it is quite logical to assume that there is a fairly close correlation between them. If all points coincide with the dash-dot line, it would indicate not a correlation but rather a functional relationship between parameters.

On the other hand, in Figure 1.6 there is lacking any appreciable relationship between weight and production cost. Therefore in this case a correlation analysis does not enable one to establish a sufficiently well-substantiated relationship between parameters.

In order to establish a correlation it is necessary to possess certain statistical data (a minimum of three or four), and it is desirable that they be distributed as uniformly as possible across the target interval.

Just as in calculating with the point method, it is necessary to select the most important machinery technical and operation parameters which affect production cost and to investigate their relationships.

In the general case the procedure of performing a correlation analysis is approximately the following: selection of dependent indicator proceeding from the aims of the investigation, selection of parameter-arguments, adoption of a hypothesis on form of relationship, selection and forming of input statistical data for subsequent mathematical model solution.

Selection of input data is of exceptional importance in constructing a correct correlation formula.

The accuracy of correlation formulas is determined in large measure by the quantity of input data utilized, since averaging of the influence of each considered parameter on the dependent variable constitutes the essence of correlation calculations. However, inclusion of a large number of input data in the calculation without thorough preliminary selection can lead to

a formula which is practically impossible to utilize even with a computer, since the number of different combinations of parameter-arguments  $\theta$  is equal to the total number of their combinations and is determined by the expression

$$\theta = \sum_{h=1}^i \frac{i!}{h!(i-h)!} = 2^i - 1, \quad (1.12)$$

where  $i$  -- total number of parameter-arguments included in the initial model;  $h$  -- number of parameters investigated simultaneously.

With 10 parameters the number of correlation formulas which must be solved will be 1,023, 1,048,575 with 20 parameters and 33,554,431 with 25 parameters, which will require an enormous time expenditure even for high-speed computers.

Therefore in order to select the most important parameters, one initially examines the influence of all selected parameter-arguments and then gradually discards those parameters which do not substantially influence the dependent indicator, until there remain those parameters which with the selected form of relationship exert the most substantial combined influence on the dependent variable. This problem is solved more simply by verifying partial correlation factors (see below).

A paired correlation between production cost and any machinery parameter can be expressed in the form of a linear equation of the type

$$y = a_0 + a_i x_i \quad (1.13)$$

or, with a curvilinear form of correlation field, in the form of an equation of the type

$$y = a_0 + a_i x_i^{b_i}, \quad (1.14)$$

where  $y$  -- dependent parameter (for example, machinery production cost);  $x_i$  -- target parameter (parameter-argument);  $a_0$ ,  $a_i$ ,  $b_i$  -- equation constant coefficients which characterize the degree of influence of the target parameter on production cost.

Correlation parameters can be obtained by various methods: least squares, point, graphic, breakdown of the aggregate of target items into groups on the basis of number of sought parameters, and subsequent presentation of the relationship between average-group indices as functional, linear programming, and others [16].

The method of least squares is the most widely employed method in solving correlation models. It corresponds better than other methods to the idea of averaging both the individual influence of the factors considered and the overall influence of those which are not taken into account; on the basis of this method one can easily determine the statistical relationship closeness characteristics required to evaluate analysis results.

The law of least squares can be formulated as follows: the sum of the squares of deviations of actual ordinates from ordinates calculated with the relationship line equation, should be least, that is

$$\sum (y_i - \bar{y}_x)^2 = \min, \quad (1.15)$$

where  $y_i$  -- actual ordinate of any point in the correlation field;  $\bar{y}_x$  -- ordinate computed by the correlation equation (let us assume that  $\bar{y}_x = a_0 + a_1 x$ ); the line over  $y$  signifies that this is the average computed ordinate, while subscript  $x$  signifies that we are dealing with a correlation between the  $y$  ordinates and the  $x$  abscissas.

We shall give an example which illustrates this law. Let the relationship between indices  $x$  and  $y$  (for example, truck load capacity in tons and its cost of production) be characterized by the following figures:

$x$	$y$
2,5	950
4,0	1400
7,0	3200
12,0	5700

We shall plot a correlation field curve from these figures (Figure 1.7). Let us assume that it has been established by examination of the essence of the phenomenon that the relationship between indices  $x$  and  $y$  should be linear, of the type

$$y = a_0 + a_1 x.$$

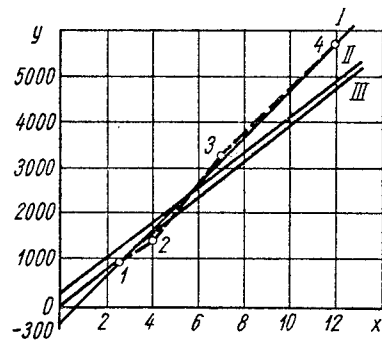


Figure 1.7. Variants of Straight Lines Expressing a Rectilinear Correlation Between the Dependent Index and Parameter-Argument

However, under the influence of many factors (for example, a difference of scale of production) points 1, 2, 3 and 4 do not fall on a straight line, that is, there is no functional relationship. Let us examine three variant straight lines of many possible ones which could substitute for actual values of  $y$ , forming a broken line (dashed line on the diagram). This substitution is necessary in order to plot a curve corresponding to the linear

relationship between  $y$  and  $x$ . Replacing the broken line with a straight line, we eliminate the influence of factors which cause deviation of actual data.

Let straight line I pass through points 1 and 4. It will intersect the Y-axis at mark -300. In this instance its equation will be expressed as follows:

$$y_1 = -300 + x \operatorname{tg} \alpha.$$

Since the straight line passes through point 4,

$$\operatorname{tg} \alpha = \frac{5700 + 300}{12} = 500;$$

then the equation of straight line I will assume the following form:

$$y_1 = 500x - 300.$$

The second possible straight line (line II) passes between all four points; its equation is

$$y_2 = 250 + 392x,$$

and of line III

$$y_3 = 0 + 393x.$$

In this case we have obtained an equation of the straight line which passes through the origin of coordinates and consequently possesses equation term  $a_0 = 0$ .

On the basis of differences in actual ordinates  $\bar{y}_i$  and ordinates calculated by the three equations  $\bar{y}_x$ , we shall determine the sum of the squares of these deviations, that is,  $\sum (y_i - \bar{y}_x)^2$ .

$x$	$y$	$\bar{y}_{x_1}$	$y - \bar{y}_{x_1}$	$(y - \bar{y}_{x_1})^2$	$\bar{y}_{x_2}$	$y - \bar{y}_{x_2}$	$(y - \bar{y}_{x_2})^2$	$\bar{y}_{x_3}$	$y - \bar{y}_{x_3}$	$(y - \bar{y}_{x_3})^2$
2,5	950	950	0	0	1200	-250	62 500	950	0	0
4,0	1400	1700	-300	90 000	1800	-400	160 000	1550	-150	22 500
7,0	3200	3150	+50	2 500	3000	+200	40 000	2700	+500	250 000
12,0	5700	5700	0	0	4900	+800	640 000	4700	+1000	1 000 000
				92 500			902 500			1 272 500

Table 1.6. Calculations of Sums of Squares of Deviations of Actual Ordinates  $y$  from Computed Ordinates  $\bar{y}_{x_1}$ ,  $\bar{y}_{x_2}$ ,  $\bar{y}_{x_3}$

Table 1.6 contains all calculations, from which it is apparent that for each straight line there is obtained a characteristic sum of squares  $\sum (y_i - \bar{y}_x)^2$ , and the smaller this sum, the better is satisfied law

$$\sum (y_i - \bar{y}_x)^2 = \min.$$

Straight line I (see Figure 1.7) has a sum of squares of deviations equal to 92,500. It is less than that of the other straight lines. Consequently, if we limit ourselves to this approximation to the minimum, replacement of individual particular values of y with values corresponding to a rectilinear relation, should be performed on the basis of the equation of straight line I:

$$y_1 = 500x - 300.$$

The closeness or strength of relationship between cost and each of the parameters, which characterizes the dispersion of the entire aggregate of actual data relative to a line computed with the correlation equation, is expressed by correlation coefficient

$$r = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}}, \quad (1.16)$$

where x and y -- features (for example, technical parameter and production cost);  $\bar{x}$  and  $\bar{y}$  -- average values of features.

x	y	(x- $\bar{x}$ )	(x- $\bar{x}$ ) <sup>2</sup>	(y- $\bar{y}$ )	(y- $\bar{y}$ ) <sup>2</sup>	(y- $\bar{y}$ )(x- $\bar{x}$ )
2,5	950	-3,9	15,21	-1860	3 459 600	7 254
4,0	1 400	-2,4	5,76	-410	168 100	984
7,0	3 200	+0,6	0,36	+390	152 100	234
12,0	5 700	+5,6	31,36	+2890	8 352 100	16 184
$\Sigma$ 25,5	11 250	—	52,7	—	12 131 900	24 656

Table 1.7. Auxiliary Computations for Calculations of Relationship Equations and Correlation Coefficient

Closeness of correlation is usually considered satisfactory if the obtained correlation coefficient values exceed 0.5.

The correlation equation with a linear form of relationship can also be obtained as follows:

$$y - \bar{y} = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sum (x - \bar{x})^2} (x - \bar{x}). \quad (1.17)$$

Let us examine the practice of calculations of formula (1.17) with the example on page 28.

Auxiliary computations for calculations of equations of relationship and correlation coefficient are summarized in Table 1.7.

Average values of  $\bar{x}$  and  $\bar{y}$  are equal to

$$\bar{x} = \frac{\sum x}{n} = \frac{25,5}{4} = 6,4;$$

$$\bar{y} = \frac{\sum y}{n} = \frac{11\,250}{4} = 2810.$$

According to the figures in Table 1.7 and formula (1.17)

$$y - 2810 = \frac{24\,656}{52,7}(x - 6,4).$$

Following transformations  $y = 468x - 184$ , that is, the obtained equation is the closest to the equation found for straight line I (see page 29).

A correlation coefficient calculated according to equation (1.16) will be

$$r = \frac{24\,656}{\sqrt{52,7 \cdot 12\,131\,900}} = 0,975,$$

that is, the obtained correlation is close to the functional ( $r=1$ ).

In the absence of a close relationship between specifications (for example, weight of machinery and its service life, size and operating speeds, etc), determined on the basis of a correlation coefficient, one can obtain production cost as an integral index with formulas of the type

$$y = \frac{\sum_1^n (a_0 + a_i x_i)}{n} \quad (1.18)$$

or

$$y = \frac{\sum_1^n (a_0 + a_i x_i^{b_i})}{n}, \quad (1.19)$$

where  $n$  -- number of parameters taken into account.

With this method of calculation, as in the point method, there occurs averaging of deviations, and the obtained result is fairly accurate. The result

becomes more accurate with an increase in the number of parameters considered and with a sufficient closeness of correlation between production cost and specifications.

A linear-type multiple correlation model can be written in the following form:

where  $a_0, a_1, a_2, \dots, a_n$  -- constants.

In this matrix the columns ( $x_{11}$ ,  $x_{12}$ , etc) are various machine parameters, and the rows ( $x_{11}$ ,  $x_{21}$ , etc) are machinery variants (modifications).

where  $\bar{y}_i$  -- calculated value of dependent variable;  $y_i$  -- actual value of dependent variable.

In place of  $y_i$  we can substitute its value proceeding from the linear form of the model; then

$$\gamma = \sum (y - a_0 - a_1 x_1 - a_2 x_2 - \dots - a_n x_n)^2 = \min. \quad (1.23)$$

We then find in sequence and equate to zero the first derivatives from quantities  $a_0, a_1, a_3, \dots, a_n$ , for example:

$$\frac{dy}{da_1} = \sum 2(y - a_0 - a_1x_1 - a_2x_2 - \dots - a_nx_n)(-x_1) = 0.$$

Removing the parentheses and carrying the constant factors beyond the sum sign, we obtain

$$-2 \sum x_1 y + 2a_0 \sum x_1 + 2a_1 \sum x_1^2 + \\ + 2a_2 \sum x_1 x_2 + \dots + 2a_n \sum x_1 x_n = 0,$$

whence

$$a_0 \sum x_1 + a_1 \sum x_1^2 + a_2 \sum x_1 x_2 + \dots + \sum x_1 x_n = \sum x_1 y$$

etc.

As a result we obtain a system of  $N$  equations with  $n$  unknowns (according to number of parameters  $a_i$ )

$$\begin{aligned} & a_0 N + a_1 \sum x_1 + a_2 \sum x_2 + . . . + a_n \sum x_n = \sum y; \\ & a_0 \sum x_1 + a_1 \sum x_1^2 + a_2 \sum x_1 x_2 + . . . + a_n \sum x_1 x_n = \sum y x_1; \\ & a_0 \sum x_2 + a_1 \sum x_1 x_2 + a_2 \sum x_2^2 + . . . + a_n \sum x_2 x_n = \sum y x_2; \\ & . . . . . \\ & a_0 \sum x_N + a_1 \sum x_1 x_N + a_2 \sum x_2 x_N + . . . + a_N \sum x_N^2 = \sum y x_N. \end{aligned}$$

If we designate  $\sum x_i x_j = a_{ij} = a_{ji}$ ,  $\sum x_i = a_{oi} = a_{oi}$ ,  $\sum y x_i = a_{iy}$  and  $N = a_{oo}$  and

utilize the matrix form of notation, then

$$\left\{ \begin{array}{ccccccc} a_{00} a_{01} a_{02} & . & . & . & a_{0n} \\ a_{10} a_{11} a_{12} & . & . & . & a_{1n} \\ a_{20} a_{21} a_{22} & . & . & . & a_{2n} \\ . & . & . & . & . \\ . & . & . & . & . \\ a_{N0} a_{N1} a_{N2} & . & . & . & a_{Nn} \end{array} \right\} \times \left\{ \begin{array}{c} a_0 \\ a_1 \\ a_2 \\ . \\ . \\ a_N \end{array} \right\} = \left\{ \begin{array}{c} a_{0y} \\ a_{1y} \\ a_{2y} \\ . \\ . \\ a_{Ny} \end{array} \right\}. \quad (1.24)$$

The coefficients and absolute terms of the obtained system form a so-called Gram matrix. Parameters  $a_i$  are found by means of system solving.

With the manual method of solution the method of square roots and method of sequential exclusion of unknowns (the Gauss method) may prove effective, and with computer solving -- the method of sequential approximations (the Seidel method) or the Gauss method.

The obtained correlation formulas should be evaluated for the purpose of determining their suitability for practical utilization.

Correlation  $\eta$  constitutes a synthesizing indicator of the quality of correlation formulas [16]. It reflects an increase in correspondence between calculated  $\bar{y}$  and actual values  $y$  of the dependent index when utilizing a correlation formula in comparison with determination of the calculated value for all items as arithmetical mean  $\bar{\bar{y}}$ .

It has been proven that

$$\sum (y - \bar{y})^2 \leq \sum (y - \bar{\bar{y}})^2. \quad (1.25)$$

The closer the relationship and the closer calculated to actual values, the smaller the fraction

$$\frac{\sum (y - \bar{y})^2}{\sum (y - \bar{\bar{y}})^2}$$

and the closer to 1 correlation

$$\eta = \sqrt{1 - \frac{\sum (y - \bar{y})^2}{\sum (y - \bar{\bar{y}})^2}}. \quad (1.26)$$

One can judge closeness of relationship by the magnitude of the correlation, by the degree of its closeness to 1.

For linear models the value of the correlation coincides with the correlation coefficient, but calculation of the latter requires a smaller number of computations.

A multiple correlation coefficient for multifactor models  $r_{1,2,3,\dots,n}$ , which reflects the closeness of relationship between index  $y$  and all others, beginning with the first and ending with the  $n$ , can be calculated in the following manner:

$$r_{1,2,3,\dots,n} = \frac{1}{\sigma_y \sqrt{N}} \sqrt{\sum_{i=1}^n a_i \left( \sum y x_i - \frac{\sum y \sum x_i}{N} \right)} \quad (1.27)$$

or

$$r_{1, 2, 3, \dots, n} = \sqrt{\frac{\sum_{i=1}^n a_i (a_{00} a_{iy} - a_{0y} a_{0i})}{\sigma_y^2 a_{0y}^2}}, \quad (1.28)$$

where  $\sigma_y$  -- root-mean-square deviation.

After performing the calculations one should determine that the results of a selective study (selected set) can extend to the entire population. In other words it is necessary to estimate the compatibility of the magnitude of the correlation factor obtained in a selective examination with the hypothesis of its equality to zero in the population. If the probability of such compatibility is low, a relationship between the dependent variable and investigated parameter-arguments in the population does indeed exist.

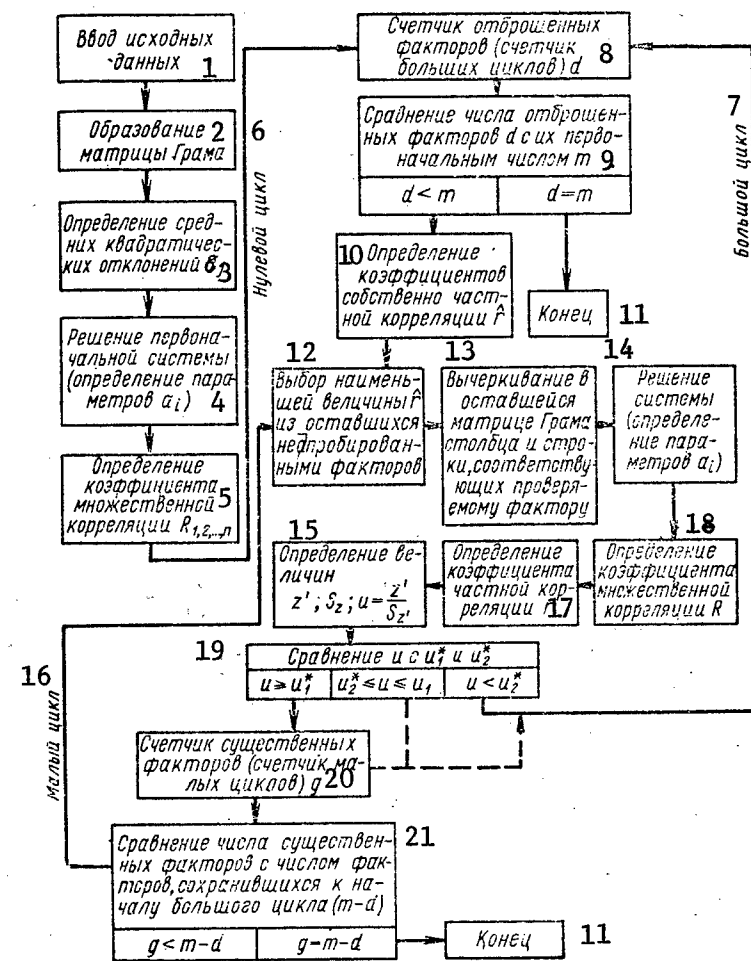


Figure 1.8. Schematic Diagram of Algorithm and Computer Program for Solving Multiple-Factor Linear Correlation Models (AINF Block Diagram)

Key to Figure 1.8 on preceding page: 1 -- input data entry; 2 -- formation of Gram matrix; 3 -- determination of root-mean-square deviations; 4 -- solution of initial system (determination of parameters  $a_i$ ); 5 -- determination of multiple correlation factor; 6 -- zero cycle; 7 -- large cycle; 8 -- discarded factor counter (large cycle counter); 9 -- comparison of number of discarded factors  $d$  with their initial number  $m$ ; 10 -- determination of partial correlation factors; 11 -- end; 12 -- selection of least quantity  $\hat{r}$  of factors remaining untested; 13 -- deletion in remaining Gram matrix of the column and row corresponding to the factor being verified; 14 -- system solution (determination of parameters  $a_i$ ); 15 -- determination of quantities; 16 -- small cycle; 17 -- determination of partial correlation factor  $r$ ; 18 -- determination of multiple correlation factor  $R$ ; 19 -- comparison; 20 -- essential factor  $g$  counter (small cycle counter); 21 -- comparison of number of important factors with number of factors retained at the beginning of a major cycle ( $m-d$ )

The methods of such a verification are described in the special literature (for example, [16]). The entire procedure of calculations and verification of multiple-factor linear correlation models when solving on a computer (AINF block-diagram) is shown in Figure 1.8 [16].

Let us examine the example of construction of a linear-type correlation equation by the Gauss method.

Let us assume that we have a limited quantity of data on several vehicle models (Table 1.8).

Table 1.8. Input Data on Truck Model

1 Модель	2 Параметры				
	3 Себесто- имость $S$ в тыс. руб./шт.	4 Грузо- подъем- ность $q$ в т	5 Вес без груза $G$ в т	6 Мощность двигателя $N_e$ в л. с.	7 Масштаб выпуска $N_{год}$ в тыс. шт/год
А	0,95	2,5	2,7	70	120
Б	1,40	4,0	4,1	97	100
В	3,20	7,0	6,4	120	30
Г	5,70	12,0	11,3	180	12

Key to table: 1 -- model; 2 -- parameters; 3 -- production cost  $S$  in thousand rub/units; 4 -- load capacity  $q$  in tons; 5 -- empty weight  $G$ , tons; 6 -- engine horsepower  $N_e$ ; 7 -- scale of production in thousand units per year

$S$  is a dependent variable. The input data matrix can be written in the form of matrix (1.21):

$$\left\{ \begin{array}{ccccc} S & q & G & N_e & N_{200} \\ 0,95 & 2,5 & 2,7 & 70 & 120 \\ 1,40 & 4,0 & 4,1 & 97 & 100 \\ 3,20 & 7,0 & 6,4 & 120 & 30 \\ 5,70 & 12,0 & 11,3 & 180 & 12 \end{array} \right\}$$

$$\begin{array}{ccccc} y & x_1 & x_2 & x_3 & x_4 \end{array}$$

In this instance the matrix is in the general form (1.24), while the desired equation is in the form

$$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4.$$

Let us examine the parameters of matrix (1.24):

$$\begin{aligned} \sum x_i x_j &= a_{ij} = a_{ji}; \\ \sum x_i &= a_{0i} = a_{i0} \text{ (see page 33);} \\ a_{00} &= \sum_1^N 1 = N = 5 \text{ (number of equations);} \end{aligned}$$

$$\begin{aligned} a_{01} = a_{10} &= \sum x_1 = 2,5 + 4,0 + 7,0 + 12,0 = 25,5; \\ a_{02} = a_{20} &= \sum x_2 = 2,7 + 4,1 + 6,4 + 11,3 = 24,5; \\ a_{03} = a_{30} &= \sum x_3 = 70 + 97 + 120 + 180 = 467; \\ a_{04} = a_{40} &= \sum x_4 = 120 + 100 + 30 + 12 = 262; \\ a_{11} &= \sum x_1^2 = 2,5^2 + 4^2 + 7^2 + 12^2 = 215,25; \\ a_{12} = a_{21} &= \sum x_1 x_2 = 2,5 \cdot 2,7 + 4 \cdot 4,1 + 7 \cdot 6,4 + \\ &\quad + 12 \cdot 11,3 = 203,55; \\ a_{13} = a_{31} &= \sum x_1 x_3 = 2,5 \cdot 70 + 4 \cdot 97 + 7 \cdot 120 + 12 \cdot 180 = 3563; \\ a_{14} = a_{41} &= \sum x_1 x_4 = 2,5 \cdot 120 + 4 \cdot 100 + 7 \cdot 30 + 12 \cdot 12 = 1054; \\ a_{22} &= \sum x_2^2 = 2,7^2 + 4,1^2 + 6,4^2 + 11,3^2 = 192,75; \\ a_{23} = a_{32} &= \sum x_2 x_3 = 2,7 \cdot 70 + 4,1 \cdot 97 + 6,4 \cdot 120 + \\ &\quad + 11,3 \cdot 180 = 3388,7; \\ a_{24} = a_{42} &= \sum x_2 x_4 = 2,7 \cdot 120 + 4,1 \cdot 100 + 6,4 \cdot 30 + \\ &\quad + 11,3 \cdot 12 = 1061,6; \\ a_{33} &= \sum x_3^2 = 70^2 + 97^2 + 120^2 + 180^2 = 61\,100; \\ a_{34} = a_{43} &= \sum x_3 x_4 = 70 \cdot 120 + 97 \cdot 100 + 120 \cdot 30 + \\ &\quad + 180 \cdot 12 = 23\,860; \\ a_{44} &= \sum x_4^2 = 120^2 + 100^2 + 30^2 + 12^2 = 25\,444. \end{aligned}$$

We then examine parameters  $\sum y x_i = a_{iy}$ :

$$\begin{aligned} a_{0y} &= \sum y = 0,95 + 1,4 + 3,2 + 5,7 = 11,25; \\ a_{1y} &= \sum x_1 y = 2,5 \cdot 0,95 + 4 \cdot 1,4 + 7 \cdot 3,2 + 12 \cdot 5,7 = 98,875; \end{aligned}$$

$$\begin{aligned}
a_{2y} &= \sum x_{2y} = 2,7 \cdot 0,95 + 4,1 \cdot 1,4 + 6,4 \cdot 3,2 + \\
&\quad + 11,3 \cdot 5,7 = 93,249; \\
a_{3y} &= \sum x_{3y} = 70 \cdot 0,97 + 97 \cdot 1,4 + 120 \cdot 3,2 + 180 \cdot 5,7 = 1611,5; \\
a_{4y} &= \sum x_{4y} = 120 \cdot 0,95 + 100 \cdot 1,4 + 30 \cdot 3,2 + 12 \cdot 5,7 = 418,4.
\end{aligned}$$

Then, utilizing the above-determined numerical values of the parameters of matrix (1.24), we obtain a system of five equations:

$$\begin{cases}
11,25 = 5a_0 + 25,5a_1 + 24,5a_2 + 467a_3 + 262a_4; \\
98,875 = 25,5a_0 + 215,25a_1 + 203,55a_2 + 3563a_3 + 1054a_4; \\
93,249 = 24,5a_0 + 203,55a_1 + 192,75a_2 + 3388,7a_3 + 1061,6a_4; \\
1611,5 = 467a_0 + 3563a_1 + 3388,7a_2 + 61100a_3 + 23660a_4; \\
418,4 = 262a_0 + 1054a_1 + 1061,6a_2 + 23860a_3 + 25444a_4
\end{cases}$$

or after simplification

$$\begin{aligned}
2,25 &= a_0 + 5,1a_1 + 4,9a_2 + 93,4a_3 + 52,4a_4; \\
9,89 &= 2,55a_0 + 21,5a_1 + 20,4a_2 + 356,3a_3 + 105a_4; \\
9,32 &= 2,45a_0 + 20,4a_1 + 19,3a_2 + 389a_3 + 106a_4; \\
16,1 &= 4,67a_0 + 35,6a_1 + 33,9a_2 + 611a_3 + 238,6a_4; \\
4,18 &= 2,62a_0 + 10,5a_1 + 10,6a_2 + 238,6a_3 + 254,4a_4.
\end{aligned}$$

We sequentially solve this system of equations in order to exclude parameter  $a_0$ :

$$\begin{aligned}
9,89 - 2,25 \cdot 2,55 &= (21,5 - 5,1 \cdot 2,55)a_1 + (20,4 - 4,9 \times \\
&\quad \times 2,55)a_2 + (356,3 - 93,4 \cdot 2,55)a_3 + (105 - 52,4 \cdot 2,55)a_4; \\
9,32 - 2,25 \cdot 2,45 &= (20,4 - 5,1 \cdot 2,45)a_1 + (19,3 - 4,9 \times \\
&\quad \times 2,45)a_2 + (389 - 93,4 \cdot 2,45)a_3 + (10 - 52,4 \cdot 2,45)a_4; \\
16,1 - 2,25 \cdot 4,67 &= (35,6 - 5,1 \cdot 4,67)a_1 + (33,9 - 4,9 \times \\
&\quad \times 4,67)a_2 + (611 - 93,4 \cdot 4,67)a_3 + (238,6 - 52,4 \cdot 4,67)a_4; \\
4,18 - 2,45 \cdot 2,62 &= (10,5 - 5,1 \cdot 2,62)a_1 + (10,6 - 4,9 \times \\
&\quad \times 2,62)a_2 + (238,6 - 93,4 \cdot 2,62)a_3 + (254,4 - 52,4 \cdot 2,62)a_4
\end{aligned}$$

and obtain a new system of four equations:

$$\begin{cases}
0,49 = a_1 + 0,93a_2 + 13,9a_3 - 3,4a_4; \\
0,52 = 1,08a_1 + a_2 + 22a_3 - 3,1a_4; \\
0,56 = 1,18a_1 + 1,1a_2 + 17,5a_3 - 0,61a_4; \\
1,71 = 2,86a_1 + 2,2a_2 + 6,1a_3 - 117,2a_4.
\end{cases}$$

We exclude parameter  $a_1$  from the obtained system of equations:

$$\begin{aligned} 0,52 - 0,49 \cdot 1,08 &= (1 - 0,93 \cdot 1,08) a_2 + (22 - 13,9 \cdot 1,08) a_3 + \\ &+ (-3,1 + 3,4 \cdot 1,08) a_4; \\ 0,56 - 0,49 \cdot 1,18 &= (1,1 - 0,93 \cdot 1,18) a_2 + (17,5 - \\ &- 13,9 \cdot 1,18) a_3 + (-0,61 + 3,4 \cdot 1,18) a_4; \\ 1,71 - 0,49 \cdot 2,86 &= (2,2 - 0,93 \cdot 2,86) a_2 + (6,1 - \\ &- 13,9 \cdot 2,86) a_3 + (-117,2 + 3,4 \cdot 2,86) a_4; \end{aligned}$$

following transformations we obtain a system of three equations:

$$\begin{cases} 0,09 = 7a_3 + 0,57a_4; \\ -0,02 = 1,1a_3 + 3,4a_4; \\ -0,68 = a_2 + 73a_3 + 231,5a_4. \end{cases}$$

Its solution provides the following coefficient values of equation (1.20):

$$\begin{aligned} a_4 &= -0,01; \\ a_3 &= 0,013; \\ a_2 &= -0,68 - 73 \cdot 0,013 + 231,5 \cdot 0,01 = 0,686; \\ a_1 &= 0,49 - 0,93 \cdot 0,686 - 13,9 \cdot 0,013 - 3,4 \cdot 0,01 = -0,36; \\ a_0 &= 2,25 + 5,1 \cdot 0,36 - 4,9 \cdot 0,686 - 93,4 \cdot 0,013 + \\ &+ 52,4 \cdot 0,01 = 0,04. \end{aligned}$$

The desired equation will assume the following form:

$$y = 0,04 - 0,36x_1 + 0,686x_2 + 0,013x_3 - 0,01x_4.$$

After replacing values  $x$  and  $y$  with the appropriate vehicle parameters (see page 37), we obtain a correlation equation for finding  $S$ :

$$\begin{aligned} S &= 0,04 + (0,686G - 0,36q) + 0,013N_e - \\ &- 0,01N \text{ thousand rub/unit.} \end{aligned} \quad (1.29)$$

We shall verify the closeness of relationship with the aid of a multiple correlation factor according to formula (1.27).

$$\bar{y} = \frac{\sum_{i=1}^n y}{n} = \frac{0,95 + 1,4 + 3,2 + 5,7}{4} = 2,81;$$

y	$y - \bar{y}$	$(y - \bar{y})^2$
0,95	-1,86	3,46
1,40	-1,41	1,99
3,20	0,39	0,15
5,70	2,89	8,35
		$\Sigma 13,95$

root-mean-square deviation will be

$$\sigma_y^2 = \frac{\Sigma (y - \bar{y})^2}{n} = \frac{13,95}{4} = 3,49;$$

$$r_{1, \dots, 4} = \sqrt{\frac{\sum_{i=1}^4 a_i (a_{00} a_{iy} - a_{0y} a_{0i})}{\sigma_y^2 a_{0y}^2}} =$$

$$= \sqrt{\frac{-0,36 (5 \cdot 98,875 - 11,25 \cdot 25,5) + 0,686 (5 \cdot 93,249 -$$

$$\rightarrow \frac{-11,25 \cdot 24,5) + 0,013 (5 \cdot 1611,5 - 11,25 \cdot 467) -}{3,49 \cdot 11,25^2} \rightarrow$$

$$\rightarrow \frac{-0,01 (5 \cdot 418,4 - 11,25 \cdot 262)}{3,49 \cdot 11,25^2},$$

$r_{1, \dots, 4} = 0.48$ , which can be considered acceptable.

Correlation equation parameters can also be obtained on the basis of the paired correlation method (by utilizing paired correlation coefficients) [16].

At the first stage one determines paired correlation coefficients  $r_{ij}$ , characterizing the closeness of relationship between  $i$  and  $j$  indices contained in the model. The calculation is performed with conventional formulas, such as (1.16) or with formulas

$$r_{ij} = \frac{\Sigma x_i x_j - \frac{\Sigma x_i \Sigma x_j}{N}}{\sqrt{\left[ \Sigma x_i^2 - \frac{(\Sigma x_i)^2}{N} \right] \left[ \Sigma x_j^2 - \frac{(\Sigma x_j)^2}{N} \right]}}, \quad (1.30)$$

or

$$r_{ij} = \frac{1}{N} \Sigma t_i t_j, \quad (1.31)$$

where  $t_i = \frac{\bar{x}_i - x_i}{\sigma_i}$  -- standardized deviation;  $\bar{x}_i$  -- arithmetic mean;

$\sigma_i$  -- root-mean-square deviation of  $i$  index.

A system of standard equations is formed on the basis of paired correlation coefficients; however, not pertaining to equation coefficients proper  $a_i$ , but rather to the same quantities in standardized scale  $\beta_i^*$

$$\left\{ \begin{array}{l} \beta_1 + \beta_2 r_{21} + \beta_3 r_{31} + \dots + \beta_n r_{n1} = r_{01} \\ \beta_1 r_{12} + \beta_2 + \beta_3 r_{32} + \dots + \beta_n r_{n2} = r_{02} \\ \dots \\ \beta_1 r_{1n} + \beta_2 r_{2n} + \beta_3 r_{3n} + \dots + \beta_n = r_{0n} \end{array} \right\}, \quad (1.32)$$

$\beta$  -- coefficients which indicate by how many units of their root-mean-square deviation the dependent variable value should change with a change in corresponding arguments also by one root-mean-square deviation. The correlation equation on a standardized scale has the form:

$$t'_0 = \beta_1 t_1 + \beta_2 t_2 + \dots + \beta_n t_n, \quad (1.33)$$

where  $t'_0$  -- calculated value of standard dependent variable deviation.

Transition from  $\beta$ -coefficients to parameters  $a_i$  takes place according to modulus

$$a_i = \beta_i \frac{\sigma_0}{\sigma_i}, \quad (1.34)$$

where  $\sigma_0$  and  $\sigma_i$  -- root-mean-square deviations of the dependent variable and  $i$  parameter of the argument.

The multiple correlation coefficient with this method of calculation can be found with formula

$$r_{1, 2, 3, \dots, n} = \sqrt{\beta_1 r_{01} + \beta_2 r_{02} + \dots + \beta_n r_{0n}}. \quad (1.35)$$

An example of derivation of a correlation formula by this method is examined on page 71.

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\* One can become acquainted with the terminology of correlation theory in the special literature, for example: Yezekiel, M., and Foks, K. A.: "Metody analiza korrelyatsiy i regressiy" [Methods of Correlation and Regression Analysis], Moscow, Statistika, 1966; Lukomskiy, Ya. I.: "Teoriya korrelyatsii i yeye primeneniye k analizu proizvodstva" [Theory of Correlation and Its Application to Production Analysis], Moscow, Gosstatizdat, 1958.

With a small examined set and a small number of parameter-arguments (up to 3 or 4) or if a computer is available, it is expedient to utilize the direct calculation method, which ensures a high degree of accuracy, while with a large volume -- the method of paired correlations, particularly with the manual method of problem solving or utilization of punched-card equipment.

In preparing input data for calculating production cost with formula (1.11), which ensures a high accuracy of calculations, it is necessary separately to determine outlays on basic materials M and wages L. The latter can easily be determined through labor requirements with formula (1.8). Outlays on materials and labor requirements of machinery manufacture can also be expressed in the form of correlations. For example, labor requirements for the manufacture of gang tools is equal to [16]

$$T_{cm} = 292,5 + 74,46n_z + 44,7n_{zn} + 35,8k + 194,5G \text{ norm-hours}, \quad (1.36)$$

where  $n_z$  -- number of power packs, units;  $n_{zn}$  -- number of clamping fixtures, units;  $k$  -- ratio of number of spindles to number of heads on machine tools;  $G$  -- machine tool weight, kg.

A power multiple factor model (with a curvilinear form of relationship) can be represented in the form

$$y = a_0 x_1^{b_1} x_2^{b_2} \dots x_n^{b_n}, \quad (1.37)$$

where  $y$  -- dependent parameter (for example, machinery manufacturing costs in rub/unit);  $x_1, x_2, \dots, x_n$  -- figured-in principal parameters;  $a_0, b_1, b_2, \dots, b_n$  -- equation constants which characterize the degree of influence of the figured-in parameters on the dependent parameter.

In order to find the parameters of a step function by the method of least squares, it is reduced to linear form by means of logarithmic operation:

$$\lg y = \lg a_0 + b_1 \lg x_1 + b_2 \lg x_2 + \dots + b_n \lg x_n. \quad (1.38)$$

We shall effect replacement of variables:

$$\begin{aligned} \lg y &= z; \\ \lg a_0 &= a'_0; \\ \lg x_1 &= u_1; \\ \lg x_2 &= u_2; \\ &\dots \\ \lg x_n &= u_n. \end{aligned}$$

Then the multiple correlation equation will assume the form

$$z = a'_0 + b_1 u_1 + b_2 u_2 + \dots + b_n u_n. \quad (1.39)$$

The equation parameters can be obtained by the above-examined methods. After finding parameters by means of taking antilogarithms, we pass to sought equation (1.37). An example of derivation of an exponential correlation formula can be found on page 75.

We shall cite examples of exponential correlation functions. The relationship between machine tool production cost  $S_n$  and their production-technical parameters can be represented in the following form [12]:

$$S_n = a_0 G^{x_p} N_{cm}^{x_N} R_{kc}^{x_R} k_{m.o}^{x_{m.o}} k_{st}^{x_{st}} D^{x_D} \text{ rub/unit}, \quad (1.40)$$

where  $a_0$  -- constant term, determined by the technical features of the manufactured machine tool;  $G$  -- machine tool total weight, kg;  $N_{cm}$  -- machine tool number from initiation of manufacture as an increasing total (takes into account the factors of series manufacture and number of years of machine tool manufacture);  $R_{kc}$  -- design complexity group;  $k_{m.o}$  -- process equipment factor;  $k_{st}$  -- standardization factor (ratio of number of standardized parts designations to total number of parts designations);  $D$  -- number of parts designations in machine tool;  $x_p, x_N, x_R, x_{m.o}, x_{st}, x_D$  -- superscripts indicating degree of influence on production cost of each of the factors considered in this formula.

For universal lathes, for example, formula (1.40) receives the following expression:

$$S_n = 1,94 G^{-0,193} N_{cm}^{0,042} k_{m.o}^{-1,121} R_{kc}^{0,49} k_{st}^{-0,994} \times D^{0,085} \text{ rub/unit}. \quad (1.41)$$

As is evident from the formula, the greatest influence on production cost is exerted by the process equipment factor (exponent 1.121), design complexity group (exponent 0.49) and standardization factor (exponent 0.994). The remaining parameters influence production cost to a significantly lesser degree. Figure 1.9 contains a nomogram which facilitates calculations on formula (1.41).

Studies conducted at the Khar'kov Engineering Economics Institute showed, for example, that the following correlation between production cost and technical factors can be established for type MP-14 DC electrical machines:

$$S_n = 226,8 G^{0,3169} n_{ob}^{-0,0038} P_m^{0,0113} V_m^{-0,0038} \text{ rub/unit}, \quad (1.42)$$

where  $G$  -- machine total weight, kg;  $n_{ob}$  -- armature rpm;  $P_m$  -- power output, in kw;  $V_m$  -- voltage.

In this case machine weight (exponent 0.3169) is the determining factor for change in production cost.

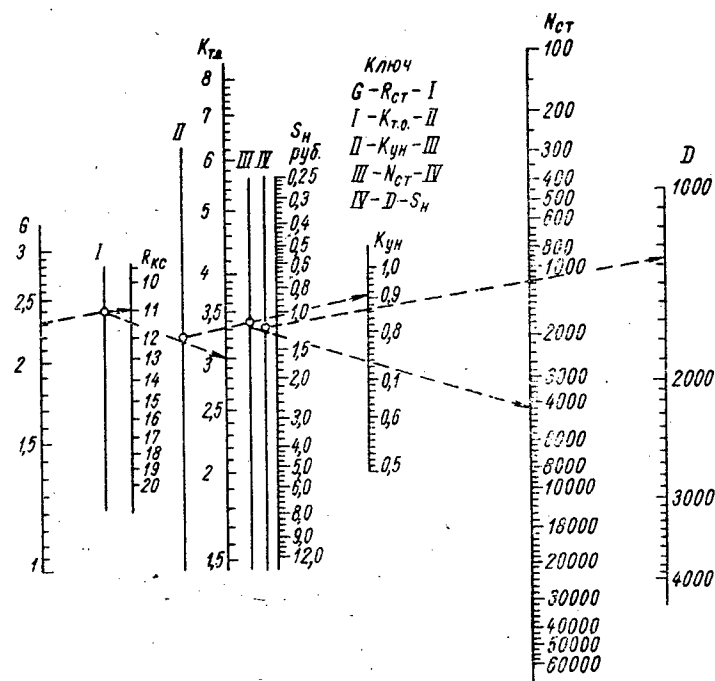


Figure 1.9. Nomogram for Determining Machine Tool Production Cost Based on Production and Technical Parameters

Usually the closest correlation exists between production cost and weight -- on the average a correlation factor of 0.6-0.9 (for tractors, for example, the correlation factor is 0.864, 0.776 for tractor motors, and 0.585 for molding machines), greater than 0.6 between production cost and complexity of repair, and also between production cost and some operating parameters. Studies have shown, for example, that the closeness of relationship between production cost and productivity for tractors is expressed by a correlation factor of 0.895, and 0.864 for molding machines [13].

Influence of scale of production on production cost. Different production scales are connected with utilization of manufacturing processes which differ in character and technological level -- casting in the floor or pressure casting, machining on universal machine tools or on automatic lathes, assembly on benches or conveyers, processing with general-purpose or special high-output equipment, etc. Employment of more sophisticated manufacturing processes leads to reduced labor requirements of manufacture and as a result to reduced production cost.

An increase in the number of units produced increases worker labor productivity due to greater work station specialization and learned worker skills in a small number of operations performed, and substantially reduces the labor

requirements of equipment setups, which in the final analysis also leads to a decrease in production cost.

An increase in the scale of production leads to a decrease in standard materials consumption figures by means of employing more precise manufacturing processes (batch-type rolling operations, precision casting, etc), which ensure that the dimensions and configuration of workpieces are closer to those of the finished parts.

One should also bear in mind that with an increase in the scale of production there occurs a decrease in the percentage share of fixed constant expenditures per unit of product.

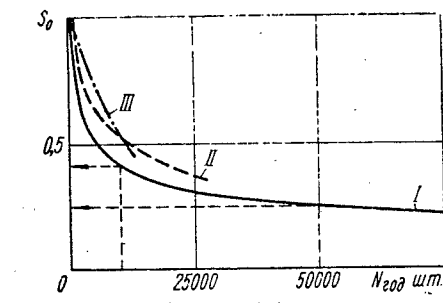


Figure 1.10. Relationship Between Relative Machinery Production Cost and Scale of Production

Key to figure: I -- trucks; II -- agricultural machinery; III -- lathes

Thus scale of production exerts great influence on the cost of manufacture both of an entire piece of machinery and of its individual units and assemblies.

If the utilized relations have been derived for any specific scale of production which differs from the assumed annual output of the machinery being designed, then one should introduce into the formula for calculating the production cost of the machinery a factor which takes into account change in production cost with a change in the scale (number of units to be produced) of manufacture. This should not be done only if this factor is taken into account in the formula structure proper [see, for example, formula (1.29)].

Figure 1.10 shows the relationship between production cost and scale of production for trucks, agricultural machinery and lathes. Gipromash suggests the following relationship between production run factor  $\delta$  and the ratio of annual output of old machinery  $N_{\text{year}_0}$  to annual output of new machinery  $N_{\text{year}_n}$ :

$N_{200_c}/N_{200_n}$	0,5	1,0	2,0	5,0	10,0	25,0	50,0
$\delta$	0,97	1,00	1,12	1,25	1,37	1,54	1,66

Figure 1.11 shows consolidated relations between the relative production cost and degree of increase of enterprise production schedules. Their value lies in taking into account a differing percentage share of outlays on materials in production cost, which more accurately reflects the type of production. They do not reflect, however, branch features, as is the case in Figure 1.9.

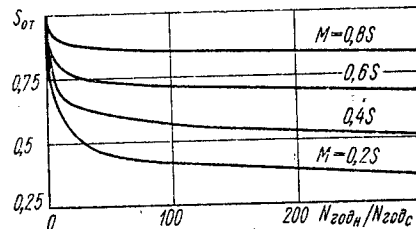


Figure 1.11. Relationship between relative production cost and production increase taking into account a differing percentage share of outlays for materials  $M$  in the structure of production cost

In order to include in the formula a factor which takes into account the number of units produced, it is necessary to know the scale of production under the conditions of which a given relationship between production cost on the one hand and technical and operation parameters on the other is obtained, and the proposed scale of manufacture for the newly-designed equipment. Then the production run factor (see Figure 1.10) is equal to

$$\delta = \frac{S_{om_n}}{S_{om_c}}, \quad (1.43)$$

where  $S_{om_n}$  -- relative production cost with the scale of manufacture established for the machinery being designed;  $S_{om_0}$  -- relative production cost at the production scale under the conditions of which the relation utilized for the calculations was obtained.

For example, to calculate the cost of producing a new truck which is to be manufactured in 50,000 unit per year, it is necessary to incorporate in the equation for calculating production cost with the manufacture of 10,000 units annually (see Figure 1.9) a factor equal to

$$\delta = \frac{0.25}{0.41} = 0.61.$$

The ambitious job of determining production run factors for various pieces of machinery and instruments was performed by L. I. Gamrat-Kurek et al [5]. Table 1.9 contains production run factors for various machines. The values of the factors are indicated in relation to the correlation between the scale of manufacture of a newly-designed machine  $N_{year_n}$  and base machine  $N_{year_0}$ .

Table 1.9. Production Run Factor  $\delta$  Values (based on machinery production cost)

1 Наименование изделий	$N_{200H}/N_{200C}$						
	2	3	5	7	10	20	50
2 Карусельные станки 153	0,84	0,76	0,67	0,61	0,56	0,47	0,38
3 Револьверные стан- ки 1336 . . . . .	0,90	0,84	0,77	0,73	0,69	0,62	0,53
4 Стиральные машины .	0,87	0,80	0,72	0,68	0,63	0,55	0,46
5 Бензиновый двигатель У5М . . . . .	0,80	0,70	0,60	0,54	0,48	0,38	0,29
6 Сельскохозяйственные машины . . . . .	0,81	0,71	0,61	0,55	0,48	0,40	0,30
7 Продовольственные ма- шины . . . . .	0,84	0,75	0,66	0,60	0,55	0,46	0,36

1 Наименование изделий	$N_{200H}/N_{200C}$				Исследован- ные пределы годовой программы 8
	100	200	500	1000	
2 Карусельные станки 153	—	—	—	—	Десятки штук 9
3 Револьверные стан- ки 1336 . . . . .	0,48	0,43	0,37	0,33	Сотни штук 10
4 Стиральные машины .	0,40	0,35	0,29	0,25	Десятки тысяч штук 11
5 Бензиновый двигатель У5М . . . . .	—	—	—	—	То же 12
6 Сельскохозяйственные машины . . . . .	0,24	0,19	0,15	0,12	»
7 Продовольственные ма- шины . . . . .	0,30	0,25	0,20	0,17	»

Key to table: 1 -- item; 2 -- 153 vertical turning and boring mills; 3 -- 1336 turret lathes; 4 -- washing machines; 5 -- U5M gasoline motor; 6 -- farm machinery; 7 -- food-processing machinery; 8 -- investigated annual production schedule limits; 9 -- tens of units; 10 -- hundreds of units; 11 -- tens of thousands of units; 12 -- same

When calculating production cost with formula (1.11), based on a preliminary determination of expenditures on materials and wages (see page 21), it is also necessary to take into consideration the difference in number of units produced of the base and new machinery. In order to calculate labor requirements, and subsequently wages as well, one can utilize labor requirements production run factor  $\delta_T$  values listed in Table 1.10.

Table 1.10. Production Run Factor  $\delta_T$  Values (machinery labor requirements)

1 Наименование изделий	$N_{200дн} / N_{200дг}$											2 Исследованные пределы годовой программы
	2	3	5	7	10	20	50	100	200	500	1000	
Фрезерные станки: 9												
6Н83 . . . . .	0,85	0,78	0,69	0,64	0,59	0,50	0,41	0,35	0,30	0,24	0,20	Сотни штук 3
6Н82 . . . . .	0,76	0,65	0,53	0,47	0,41	0,31	0,22	0,17	0,13	0,09	0,07	Тысячи штук 4
10 Карусельные станки 153 . . . . .	0,77	0,66	0,54	0,48	0,42	0,32	0,23	0,17	0,13	0,09	0,07	Десятки штук 5
11 Револьверные станки 1336 . . . . .	0,88	0,81	0,74	0,69	0,64	0,57	0,48	0,42	0,36	0,30	0,26	Сотни штук 3
12 Стиральные машины . . . . .	0,87	0,80	0,72	0,68	0,63	0,55	0,46	0,40	0,35	0,29	0,25	Десятки тысяч штук 6
Дизели малые 13 . . . . .	0,80	0,70	0,59	0,53	0,47	0,37	0,27	0,22	0,17	0,13	0,10	То же 7
14 Бензиновый двигатель У5М . . . . .	0,79	0,69	0,58	0,52	0,46	0,36	0,23	0,21	0,17	0,12	0,10	»
15 Компрессоры, насосы, ткацкие станки . . . . .	0,87	0,80	0,72	0,68	0,63	0,55	0,46	0,40	0,35	0,29	0,25	100—25 000 шт.
16 Краны, экскаваторы . . . . .	0,87	0,80	0,72	0,68	0,63	0,55	0,46	0,40	0,35	0,29	0,25	10—2000 шт.
17 Трактор ДТ-54: по механической обра-												
18 ботке . . . . .	0,85	0,78	0,69	0,64	0,59	0,50	0,41	0,35	0,30	0,24	0,20	Десятки тысяч комплектов 8
19 по обработке давлением . . . . .	0,77	0,66	0,54	0,48	0,42	0,32	0,23	0,17	0,13	0,09	0,07	То же
20 Металлорежущие станки (среднее) . . . . .	0,80	0,70	0,60	0,54	0,48	0,38	0,29	0,23	0,18	0,14	0,11	100—5000 шт. (21)

Key to table: 1 -- item; 2 -- investigated annual production run limits;  
3 -- hundreds of units; 4 -- thousands of units; 5 -- dozens of units; 6 -- tens of thousands of units; 7 -- same; 8 -- tens of thousands of sets; 9 -- milling machines; 10 -- vertical boring and turning mills; 11 -- turret lathes; 12 -- washing machines; 13 -- small diesel motors; 14 -- gasoline engine; 15 -- compressors, pumps, looms; 16 -- cranes, excavators; 17 -- tractor; 18 -- machining; 19 -- pressure shaping; 20 -- metal-cutting machine tools (average); 21 -- units

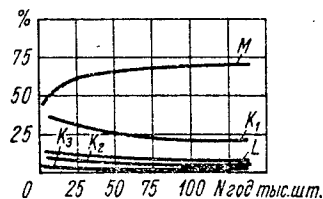


Figure 1.12. Relationship Between Structure of Truck Production Cost and Annual Truck Production Schedule

Key to figure: M -- expenditures on basic materials and component items;  
K -- shop indirect expenditures; L -- basic wages of production workers;  
K<sub>2</sub> -- general plant outlays; K<sub>3</sub> -- nonproduction outlays

Utilization of figures on structure of production cost for calculations. The relations shown on the graph (Figure 1.11) become even more valuable for calculations if figures are available on the structure of machinery production cost and the scale of production. Figure 1.12 shows how the structure of truck production cost changes in relation to the annual production schedule. It is important to note that change in the percentage share of outlays on materials in production cost, particularly with a comparatively small scale of production, occurs fairly intensively.

A combined analysis of figures 1.11 and 1.12 is extremely useful for refining calculations of production cost applicable to a given scale of production. For example, if 50,000 trucks per year are to be produced, then according to Figure 1.12 one can expect the share of outlays on materials, samimanufactures, and purchased items to be approximately 60% of production cost. In connection with this one should utilize the curve  $M=0.6S$  to calculate factor  $\delta$  with the curves contained in Figure 1.11. On the basis of the three above-described methods of calculating production cost at the early stage of preproduction design, during preliminary design and preparation of preliminary drawings, the following conclusions can be drawn:

a) the simplest methods of obtaining production cost in the absence of a sufficient quantity of input data on design are the method of calculation according to specific indices and the point method, with preference going to the latter, since it takes into consideration a greater number of machine parameters; however, neither method can ensure securing sufficiently accurate results due to the imperfection of mathematical processing of the input data;

b) the most accurate method of calculating production cost at this stage of design, which requires, however, more statistical information and a greater volume of calculations, and in many cases the employment of a computer in order to obtain the mathematical relationship, is the correlation method; it can also be successfully employed in subsequent stages of design;

c) utilization of multiple correlation functions makes it possible not only to calculate production cost with a fairly high degree of accuracy but also to determine the degree of influence of a given parameter on production cost, which enables the designer, utilizing feedback, to devote particular attention to the most important parameters, as a result obtaining higher technical-economic effectiveness of the designed item;

d) correlation formulas make it possible quickly to elucidate the influence of various changes made in the design parameters, on the materials requirements, labor requirements and production cost of a piece of machinery, and to determine the most optimal design solutions;

e) with all this one should bear in mind that even utilization of correlation functions at this stage of design will make it possible to determine a production cost which will be only a first approximation of a machine's

actual production cost, since the volume of input information is small, and in particular there is lacking information (or there is very little available) on the structural elements of the designed piece of machinery (units, assemblies, parts); this information can be obtained only by advancing the design process.

### 3. Method of Calculating Production Cost at the Preliminary Engineering Stage

The unit-by-unit and assembly-by-assembly method of calculating production cost. At the preliminary engineering stage it is entirely possible and correct to utilize any of the above-discussed methods of calculating production cost. However, the availability at this stage of a large quantity of new data (see Table 1.1), and in particular elaborated drawings of units and assemblies, specifications on purchased items and specifications on materials, makes it possible to apply more precise methods of calculating the production cost of the new piece of machinery.

As was already noted, utilization of input data as a whole on a piece of machinery, without a breakdown by individual units, makes it impossible to perform precise calculations of production cost. In such calculations it is impossible to take into account specific changes made by designers in specific units and assemblies as well as the replacement of individual machinery units by totally new units.

Let us assume that it is proposed to employ a hydraulic transmission in a new truck design in place of a standard transmission (in which, as we know, a torque converter is a totally new element), with power steering to be incorporated in the steering gear design in order to make things easier on the driver, plus the adoption of disc brakes to replace drum brakes. How should these changes be reflected in production cost calculations? None of the above calculation methods, not one of the above formulas enables us to take into account with any adequate degree of accuracy the above-mentioned changes, since at the preliminary design stage, and in some cases at the preliminary drawings stage as well there is a lack of precise parameters of individual units and assemblies.

At the preliminary engineering stage, however, consolidated calculations of production cost for the new item as a whole are unacceptable, since there is a possibility of refining them significantly. At this stage (and in many cases at the preliminary drawings stage as well) it is advisable to perform production cost calculations not for the entire design as a whole but for individual units and assemblies. For each of them one can find the most characteristic relations which link the principal technical and production parameters of a unit or assembly known at a given stage with the cost of producing them. Then, in calculating the production cost of the entire piece of equipment one could determine in advance the cost of producing its units and assemblies on the basis of the derived relations (presented in graphic form or as formulas), subsequently figuring in expenditures for overall assembly with the aid of a factor.

Overall assembly costs depend on the type of production and complexity of the machinery involved, and may range from 1.1 to 1.4. The closer the type of production approaches single-unit manufacture, and the more complex the piece of machinery is, the greater will be the value of this factor.

Thus the production cost of a piece of machinery will consist of two components: the cost of producing the assemblies and units, taking into account the scale of their production and the plan-specified (or wholesale-release in a first approximation) price of purchased units and assemblies. Calculation of the production cost of a newly-designed piece of machinery  $S_n$  can be performed with the following formulas:

$$S_n = \mu \left( \sum_1^m S'_{azp} \delta + \sum_1^n C_{azp_n} \right) \text{ rub/unit} \quad (1.44)$$

or

$$S_n = \mu \left( \sum_1^m S_{azp} + \sum_1^n C_{azp_n} \right) \text{ rub/unit}, \quad (1.45)$$

where  $\mu$  -- factor taking into consideration overall assembly costs;  
 $S'_{un}$  -- production cost of unit or assembly in rub/unit, under the condition of agreement between the projected scale of production and the scale under conditions of which the relation utilized for the calculations was obtained (let us assume that the specific cost per kg of reduction gear weight with an output of 25,000 units per year is equal to 1 rub; if the reduction gear weighs 100 kg, then with a calculation based on utilization of specific production cost we can assume that its cost will be 100 rubles with an output of 25,000 units per year);  $\delta$  -- production run factor [see formula (1.43)];  $S_{un} = S'_{un} \delta$  -- production cost of a unit or assembly with the specified production schedule, in rub/unit;  $C_{un_n}$  -- plan-specified (or wholesale-release) price of units and assemblies obtained through cooperative manufacture (obtained on the basis of price lists or wholesale-release prices or from cooperative-manufacture delivery lists), in rub/unit;  $m$  -- number of machinery units and assemblies manufactured at the plant;  $n$  -- number of purchased units (assemblies) in the machinery.

The existence of differentiated indicators of production cost, materials requirements and labor requirements of individual units and assemblies or their specific values makes it possible to obtain significantly more reliable relations than those examined above for a piece of machinery as a whole.

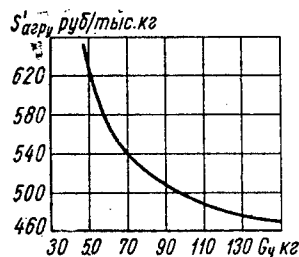


Figure 1.13. Relationship Between Specific Cost of Manufacturing Reduction Gears and Weight (Average Outlays on Materials 56%, Average Outlays on Production Worker Wages 11%)

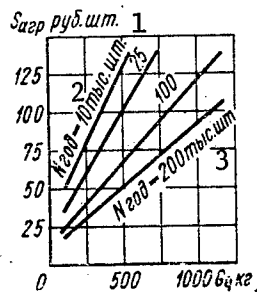


Figure 1.14. Relationship Between Cost of Producing Truck Frames and Their Weight With Various Production Schedules

Key to figure: 1 -- rub/unit; 2 -- 10,000 units; 3 -- 200,000 units

Even a small (3 to 4) quantity of data on the production cost of units or assemblies of a specified type makes it possible to derive relations similar to those contained in figures 1.13 [3], 1.14, and 1.15 [3], or to employ the method of calculation on specific indices.

The existence of materials specifications at the preliminary engineering stage makes it possible to utilize in a better-substantiated manner the design materials requirements indicator for production cost calculations with formula (1.11), calculating unit production cost  $S'_{un}$  with this formula. In addition it is possible to utilize with a sufficient degree of accuracy a very simple formula to calculate unit or assembly production cost:

$$S'_{azp} = \frac{M_1 + \sum_1^n C_{\partial n}}{m_0} 100, \quad (1.46)$$

here  $M_1$  -- outlays on basic materials expended in producing a unit or assembly, in turn determined with the formula

$$M_1 = \sum_1^m \frac{G_{n_i} C_{m_i}}{k_p} \text{ rub/unit}, \quad (1.47)$$

where  $G_{n_i}$  -- net weight of materials of a given cost group in the unit or assembly without purchased parts (determined from the drawings), in kg;  $C_{m_i}$  -- average cost per kg of materials of a given cost group (determined from wholesale price lists on the basis of specifications), in rubles;  $k_p$  -- a factor which takes into account the correlation between net weight  $G_n$  and calculation of materials  $G_p$  (in consolidated calculations  $k_p$  values are taken in a range of 0.5-0.7, and up to 0.9 for the most advanced processes in mass production); it is determined with formula

$$k_p = \frac{G_{q1}}{G_{pi}} < 1, \quad (1.48)$$

where  $G_{pi}$  -- expenditure of materials of a given cost group, in kg;  $m$  -- number of materials cost groups in unit or assembly;  $C_{dn}$  -- expenditures on purchased parts of a unit or assembly, in rub/unit;  $n$  -- list of purchased items in unit or assembly;  $m_0$  -- percentage share of outlays on materials in cost of unit or assembly; determined proceeding from the cost structure of analogous units or assemblies with a given scale of production (Figure 1.16), %.

In determining net weight from drawings one can employ various formulas constructed applicable to specific types of units and assemblies. For enclosed gear reducers, for example, an approximate weight calculation can be made with the formula

$$G_u = \phi_p \gamma V \cdot 10^{-3} \text{ kg}, \quad (1.49)$$

where  $\gamma$  -- average specific weight ( $\sim 7.3$ ) in  $\text{g/cm}^3$ ;  $\phi_p$  -- space factor, obtained from graphs in relation to the type of reduction gear and its basic dimensions (Figure 1.17);  $V$  -- nominal volume of reduction gear (based on principal dimensions), in  $\text{mm}^3$ .

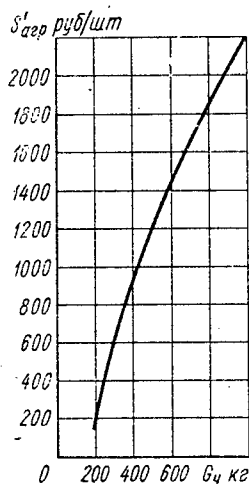


Figure 1.15. Relationship Between Reduction Gear Cost of Manufacture and Its Weight

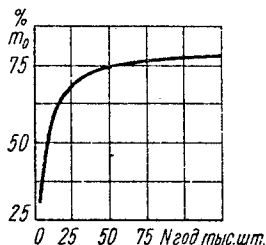


Figure 1.16. Relationship Between Percentage of Outlays on Basic Materials in the Cost of Truck Frames and the Annual Production Schedule

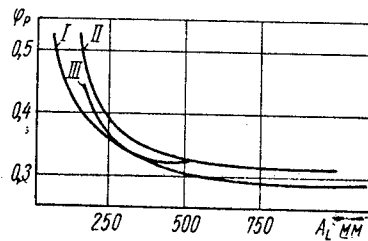


Figure 1.17. Relationship Between Base Factor and Spur-Type Reduction Gear Distance Between Centers

Key to figure: I -- single-stage; II -- two-stage; III -- three-stage

Calculation of production cost at this stage of design can be refined if it is possible to utilize relations of the formulas (1.3) and (1.4) type to determine outlays on materials, semimanufactures and purchased items and on basic production worker wages, while obtaining production cost with formula (1.11). Finding labor requirements  $T$  or labor requirements specific value  $t_{yd}$  presents the main difficulty in a refined calculation of this kind.

For consolidated calculations it is recommended that the labor requirements of designed assemblies and units  $T_{un_n}$  be obtained with formulas of the formula (1.9) type:

$$T_{azp_n} = T_{azp_c} \sqrt[3]{\frac{G_{un}^2}{G_c^2}} \text{ norm-hr/unit, (1.50)}$$

where  $T_{un_0}$  -- labor requirements of prior-manufactured geometrically-similar unit or assembly in norm-hours;  $G_{nn}$  -- net weight of newly-designed unit or assembly, kg;  $G_{n_0}$  -- net weight of prior-manufactured unit or assembly in kg (in this formula taken under conditions of full-scale production).

Relations similar to those indicated in Figure 1.18 [3] can be elaborated for materials requirements and labor requirements.

The previously-examined point method can also be successfully employed in calculating the production cost of units and assemblies. For this it is necessary to take three or four basic technical and operation parameters of a unit or assembly (for reduction gears, for example, net weight, maximum transferred torque, maximum gear ratio, number of gears; for frames, girders, and other metal structures -- net weight, number of components, complexity category), to construct a point system for them within the limits of a given scale of production (Figure 1.19) and to calculate unit cost  $S'_{un}$  in conformity with the examined method. For example, if we are designing a five-speed standard truck transmission weighing 100 kg, with a maximum torque of 200 kgm and a maximum gear ratio of 7:1, then according to Figure 1.19 the point total will be  $1.2+1.6+2+1.4=6.2$ .

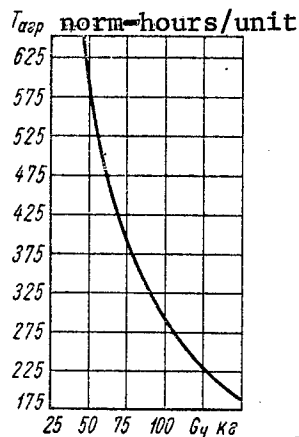


Figure 1.18. Relationship Between the Labor Requirements of Manufacturing 1 Ton of Reduction Gears and Their Weight

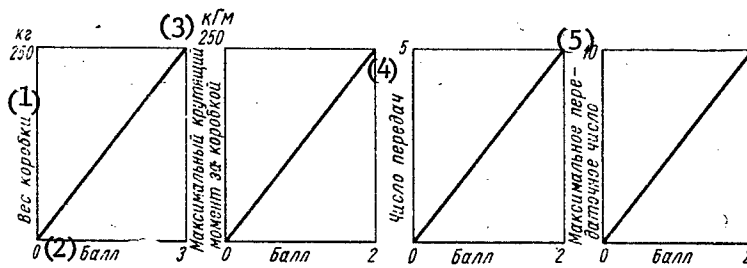


Figure 1.19. Point System for Calculating the Production Cost of Truck Transmissions

Key to figure: 1 -- weight of transmission; 2 -- points; 3 -- maximum torque; 4 -- number of speeds; 5 -- maximum gear ratio

With an average value factor of 9 rub/point for the given scale of production, the production cost of the designed transmission will be  $6.2 \times 9 = 55.8$  rubles.

Scale of production can be directly incorporated into the point system in the form of a separate curve. Then one can immediately obtain quantity  $S_{un}$ .

At the preliminary engineering stage sufficiently reliable unit-by-unit and assembly-by-assembly correlation functions can be derived in order to calculate production cost. One should note, however, that such systematized relations are in practice encountered very rarely. It is the task of scientific research institutes and design offices to produce them. Accomplishment of this task would considerably facilitate the performance of economic calculations in engineering design and would greatly improve the accuracy of their results.

Influence of scale of production on production cost; utilization of data on structure of production cost for calculations. In calculating the production cost of individual units and assemblies it is essential to take into consideration that the scale of their manufacture may differ substantially from the scale of manufacture of the designed item. Calculators and computers, for example, frequently consist of a large number of precisely the same or highly-standardized units, while a single truck requires 4 to 6 and sometimes considerably more identical reduction gears, brake components, tires, etc. If in calculating their production cost one adopts a production run factor corresponding to the specified production figure on the designed vehicle, the error will be so substantial that it may totally distort the results of a subsequent technical-economic analysis.

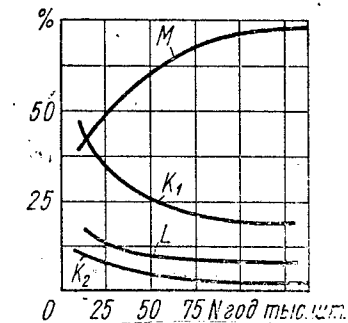


Figure 1.20. Relationship Between Structure of Cost of Producing Propeller Shaft and Universal Joint Units and Annual Output Schedule

Key to figure: M -- outlays on basic materials and component items; L -- wages of basic production workers;  $K_1$  -- shop indirect expenditures;  $K_2$  -- general plant indirect expenditures

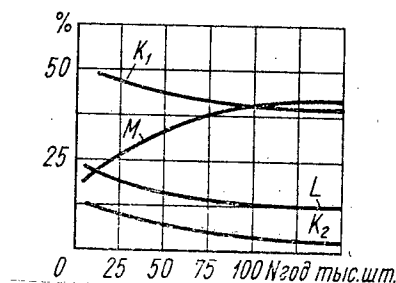


Figure 1.21. Relationship Between Structure of Cost of Producing Transmissions and Annual Output Schedule

Key to figure: M -- outlays on basic materials and component items; L -- wages of basic production workers;  $K_1$  -- shop indirect expenditures;  $K_2$  -- general plant indirect expenditures

It is also necessary to take into account possible standardization of units and assemblies for several pieces of equipment and employment in a newly-designed piece of equipment assemblies and units of other machinery which are already in production, since this increases their scale of manufacture and as a consequence reduces the cost of manufacture.

In calculations of production cost of assemblies and units it is useful to utilize figures on the structure of production cost, employing the method described on page 49. Figures 1.20 and 1.21 contain as examples graphs illustrating the character of change in the structure of cost of producing driveshaft-universal joint assemblies and truck transmissions in relation to annual production figures.

Thus at the preliminary engineering stage it is expedient, in order to refine production cost calculations, to shift from overall relations for a piece of equipment as a whole to unit-by-unit and assembly-by-assembly relations. This will make it possible to take into account in the newly-designed piece of equipment to a substantially greater degree the influence of specific design decisions on machinery production cost.

#### 4. Method of Calculating Production Cost During the Detailed Engineering Stage

Method of calculating production cost part by part. At the detailed engineering stage there is a greater capability for precise calculation of the cost of producing a new piece of equipment. Here one can utilize any of the above-examined calculation methods. The availability of design-technical data on parts (see Figure 3 and Table 1.1) will make it possible to obtain summary figures on production cost which approximate plan-specified cost, which will be calculated in the process of preproduction engineering.

At this stage the production cost of each unit or assembly can be calculated as the sum of the production costs of the parts comprising the unit or assembly, employing the following formulas [analogous to formulas (1.44) and (1.45)]

$$S_{azp} = \mu \left( \sum_1^m S'_d \delta + \sum_1^n C_{\partial n} \right) \text{ rub/unit} \quad (1.51)$$

or

$$S_{azp} = \mu \left( \sum_1^m S_d + \sum_1^n C_{\partial n} \right) \text{ rub/unit}, \quad (1.52)$$

where  $\mu$  -- coefficient taking into account expenditures on assembly ( $\mu=1.1-1.4$ ; see page 51);  $S'_d$  -- cost of producing the part, under the condition of agreement between the proposed scale of production and the production scale at which the relation was obtained which was utilized for the calculations, in rub/unit (for reduction in the number of calculations see Chapter III);  $\delta$  -- production run factor [see formula (1.43)];  $S_d = S'_d \delta$  -- cost of producing the part with the specified production schedule in rub/unit;  $m$  -- number of parts in unit or assembly, with the exception of parts obtained through co-operative manufacture;  $n$  -- number of purchased parts in the unit or

assembly;  $C_{d_n}$  -- plan-specified (or, in a first approximation, wholesale-release) price of parts obtained on the basis of cooperative manufacture (determined on the basis of wholesale-release price lists or cooperative manufacture delivery lists), in rubles per unit.

In calculating the production cost of units and assemblies on the basis of this formula, the cost of fasteners can be figured as a total, in the form of factor  $\eta$ , not including them in  $C_{d_n}$ . Then

$$S_{azp} = \mu \eta \left( \sum_1^m S'_d \delta + \sum_1^p C_{d_n} \right), \quad (1.53)$$

where  $\eta$  -- a factor which takes into account outlays on purchased fasteners ( $\eta=1.02-1.05$ );  $p$  -- number of purchased parts in the unit or assembly excluding fasteners.

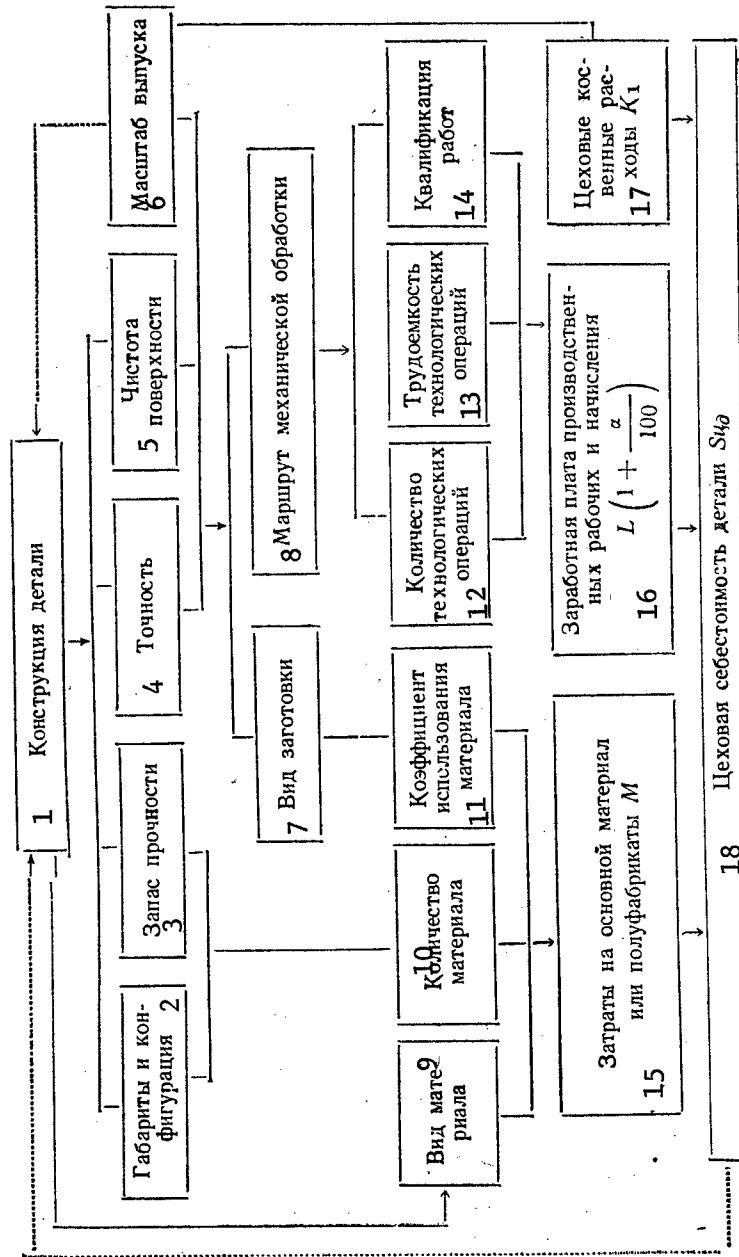
Figure 1.22 presents the aggregate of principal factors affecting the shop cost of producing a part. It is hardly possible to take into account in production cost calculations all factors indicated in the figure at this stage of preproduction engineering. In particular, when utilizing formula (1.11) major difficulties arise in calculating production worker wages, since the number of process operations, their labor requirements, and required level of worker skills will become known only in the process of preproduction engineering.

Therefore at the detailed engineering stage, for calculating the production cost of parts one can employ the methods examined previously, of course obtaining considerably more precise relations between production cost and basic factors than for units or a piece of equipment as a whole.

The diagram also presents feedback, that is, influence on the design both by scale of production and by obtained figures on production cost. If the calculated production costs of parts (and subsequently units and the equipment as a whole) do not make it possible to obtain high technical-economic design indices, the design process should be continued, and the cycle is repeated until the required results are obtained.

Calculation of cost of producing parts  $S'_d$  on the basis of specific indices. An approximate calculation of the cost of producing parts for specified production scales on the basis of specific indices should be performed utilizing specific correlations between production cost and expenditure of materials or net weight. It is of course desirable thereby to take into account the influence on production cost of required machining precision, surface finish and other manufacturing process factors.

Figure 1.22. Relationship Between the Production Cost of a Part and Technical and Production Factors: —————> Direct link;  
—————> Feedback



Key to figure: 1 -- part design; 2 -- size and configuration; 3 -- safety factor; 4 -- precision; 5 -- surface finish; 6 -- scale of production; 7 -- type of workpiece; 8 -- machining routing; 9 -- type of material; 10 -- quantity of material; 11 -- material utilization factor; 12 -- number of process operations; 13 -- labor requirements of process operations; 14 -- job skill level; 15 -- cost of basic material or semimanufacture M;

(Key to Figure 1.22, cont'd) 16 -- wages of production workers and social insurance contributions; 17 -- shop indirect expenditures; 18 -- shop cost of producing part

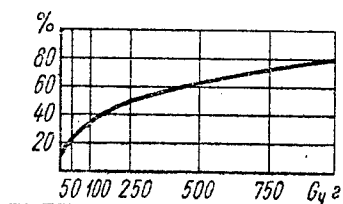


Figure 1.23. Relationship Between Specific Value of Expenditures on Materials in the Cost of Producing Plastic Parts and Their Weight.

The correlation between the cost of producing a part and its net weight can be represented as

$$S'_0 = \frac{G_n C_m}{m_0 k_p} 100 \text{ rub/unit}, \quad (1.54)$$

where  $G_n$  -- net weight of part according to drawing, kg;  $C_m$  -- cost per kg of material, in rubles;  $m_0$  -- percentage share of outlays on material in cost of producing part; it is determined proceeding from the structure of the cost of producing similar parts with a given scale of production (see Figure 1.23 [6]), %;  $k_p$  -- factor which takes into account the correlation between net weight and expenditure of material -- material utilization factor (see tables 1.11, 1.12, and 1.13).

As an example we list below  $m_0$  values for several types of plastic parts and semimanufactures:

Press-forged parts .....	44
Cast parts .....	42
Polyvinyl chloride pipe .....	44
Polyethylene film (experimental production) .....	28
Polyethylene pipe (experimental production) .....	17

Material utilization factors are determined primarily by part configuration and the type of workpiece employed. In small-series production, for example, the metal utilization factor for bevel gears is 0.3 with a gear blank of rolled stock, and 0.45 with a stamped blank; the figures are 0.24 and 0.4 respectively for double-toothed spur gears.

Table 1.11. Coefficient  $k_p$  Values for Machine-Building Parts in Various Types of Industrial Operations

Заготовка детали 1	2 Типы производства		
	3 Мелко-серийное	4 Крупно-серийное	5 Массовое
Горячекатаная сталь 7 . . . . .	0,6	0,8	0,8 и более
Холоднокатаная сталь 8 . . . . .	0,4	0,5	0,75 и более
Прокат цветных металлов 9 . . . . .	0,5	0,6	0,75 и более
Чугунная отливка . . . . 10 . . . . .	0,6	0,8	0,9 и более
Стальная отливка . . 11 . . . . .	0,6	0,75	0,9 и более
Цветная отливка . . . 12 . . . . .	0,4	0,45	0,7 и более

Key to table: 1 -- stock, workpiece; 2 -- types of production; 3 -- small-series; 4 -- large-series; 5 -- mass; 6 -- and more; 7 -- hot-rolled steel; 8 -- cold-rolled steel; 9 -- nonferrous rolled stock; 10 -- iron casting; 11 -- steel casting; 12 -- nonferrous casting

Table 1.12. Coefficient  $k_p$  Values for Several Machine Building Parts Under Conditions of Small-Series Production

Наименование деталей 1	2 Способ получения заготовки	$G_d$ в кг	$k_p$
Болты и гайки 3 . . . . .	12 Штамповка	0,02—0,2	0,36—0,4
То же . . . . . 4 . . . . .	То же	0,25—0,8	>0,4
» . . . . .	»	1—10	>0,45
Валики: 5	»	До 1	>0,5
мелкие 6 . . . . .	»	» 10	>0,4
средние 7 . . . . .	13 Поковка	50—300	0,3—0,37
Валы крупные 8 . . . . .	То же	До 1	0,4
9 Зубчатые колеса (стальные)	14 Прокат	До 1	0,33—0,36
То же . . . . .	Штамповка	» 20	0,25—0,32
» . . . . .	15 Литье	50—500	>0,33
Цилиндры крупные 10 . . . . .	Центробежное	До 1000	
Червячные шестерни 11 . . . . .	16 литье	До 3	0,7
То же . . . . .	Фигурное центробежное литье 17	19	0,25
» . . . . .	Литье в землю 18	Св. 3	0,7
	Фигурное центробежное литье 17	20	

Key to table: 1 -- parts; 2 -- method of obtaining workpiece; 3 -- bolts and nuts; 4 -- same; 5 -- shafts; 6 -- small; 7 -- medium; 8 -- large shafts; 9 -- gears (steel); 10 -- large cylinders; 11 -- worm gears; 12 -- stamping; 13 -- forging; 14 -- rolled stock; 15 -- casting; 16 -- centrifugal casting; 17 -- shaped centrifugal casting; 18 -- casting in the floor; 19 -- up to; 20 -- more than

Table 1.13. Coefficient  $k_p$  Values for Plastics when Processed Into Finished Products [6]

Наименование деталей 1	Методы переработки 2 пластмасс	$k_p$
Детали из фено- и аминопластов, волокнитов, стекловолокнитов 2a . .	7 Компрессионное прессование	0,89—0,91
Детали из термопластов 3 . . .	8 Литье под давлением	0,93—0,95
4 Трубы, шланги и листы из полиэтилена, трубы из полихлорвинила	9 Экструзия	0,95
5 Детали из полиэтилена . . . . .	10 Выдувание	0,95
6 То же . . . . .	11 Вакуум-формование	0,95

Key to table: 1 -- parts; 2 -- plastic processing methods; 2a -- parts of phenoplasts and aminoplasts, fiber-filled molding material, fiberglass; 4 3 -- parts of thermoplasts; 4 -- polyethylene pipes, hoses and sheets, polyvinyl chloride pipe; 5 -- polyethylene parts; 6 - same; 7 -- compression molding; 8 -- pressure molding; 9 -- extrusion; 10 -- inflation; 11 -- vacuum molding

For more approximate calculations one can utilize the correlations between the weight and cost of parts available in various branches of machine building (see tables 1.14 and 1.15 and figures 1.24-1.29) or derive such relationships on the basis of available statistical materials.

Table 1.14. Average Cost of Producing 1 Ton of Parts, of Thermosetting Plastics, in Rubles [5]\*

1 Вес детали в кг	2 Группа сложности деталей		
	3 Простые	4 Средней сложности	5 Сложные
6 Детали из пресспорошка К-18-2:			
До 10 . . . . .	1300	2025	3725
11—100 . . . . .	945	1405	1855
101—200 . . . . .	720	855	1395
7 Детали из волокнита:			
До 10 . . . . .	2190	3230	4110
11—60 . . . . .	1830	2610	3670
61—200 . . . . .	1550	1990	2590
201—600 . . . . .	1310	1790	2190

\* Цены на отливки поковки, штамповки из металлов см. в приложениях 2 и 3.

Key to table: 1 -- weight of part, kg; 2 -- parts complexity group; 3 -- simple; 4 -- medium complexity; 5 -- complex; 6 -- parts of K-18-2 molding powder; 7 -- parts of fiber-filled molding material; \* -- for prices on metal castings, forgings, stampings see appendices 2 and 3

Table 1.15. Approximate Cost of Manufacturing 1 kg of Parts, in rubles [2]

1 Деталь	2 Заготовка	3 Чистый вес в кг	4 Тип производства		
			5 Серийное	6 Крупно- серийное	7 Массовое
8 Шестерня	Поковка, сталь 45, 40X	До 2	1,05/10*	0,79/50	0,7/300
9 То же	То же	10,2—20	0,62/19	0,47/50	0,42/100
»	»	Св. 30	0,61/1	0,44/5	0,42/25
»	16 Отливка, сталь 55Л	До 2	0,92/10	0,83/50	0,74/140
Звездочки для	Отливка	» 1	0,56/20	—	—
10 цепей	17 в землю, СЧ 18-36	» 1	—	0,47/100	0,41/500
То же	18 Отливка в оболочку, СЧ 18-36	» 2	0,46/20	—	—
»	17 Отливка в землю, СЧ 18-36	» 2	—	0,46/100	0,41/500
»	18 Отливка в оболочку, СЧ 18-36	До 0,5	1,59/250	0,95/375	0,79/575
11 Втулка	Отливка, СЧ 15-32	» 1	1,04/200	0,94/350	—
То же	19 Прокат, сталь 45	» 1	—	—	0,41/500
»	20 Трубка тянутая	» 1	2,01/76	1,82/200	1,63/300
»	21 Отливка, бронза	» 5	0,58/50	0,32/200	0,27/300
12 Валы	22 Прутки, сталь	» 2	0,35/110	0,22/300	0,20/700
Валики шарнир- ного соединения	9 То же	» 5	0,80/50	0,61/145	0,52/230
13 Корпусы под- шипников	16 Отливка, СЧ 18-36	20—30	0,46/36	0,40/68	0,36/122
14 Скользящие скольжения	9 То же				

\* В знаменателе — годовой выпуск в тыс. шт.

Key to table: 1 -- part; 2 -- workpiece; 3 -- net weight in kg; 4 -- type of production; 5 -- series; 6 -- large-series; 7 -- mass; 8 -- pinion; 9 -- same; 10 -- sprocket wheels; 11 -- bushing; 12 -- shafts; 13 -- articulated joint shafts; 14 -- sliding bearing shells; 15 -- steel forging; 16 -- steel casting; 17 -- floor casting; 18 -- shell-mold casting; 19 -- rolled steel; 20 -- drawn tube; 21 -- bronze casting; 22 -- steel rod; \* -- number in denominator -- annual output in thousand units

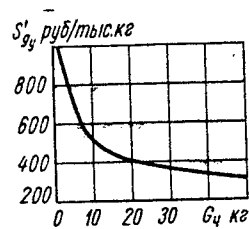


Figure 1.24. Relationship Between Specific Cost of Producing Bearing Shells of SCh 18-36, SCh 15-32 and SCh 12-28 Cast Iron and Their Weight (average outlays on materials 50%, average outlays on production worker wages 14% [13])

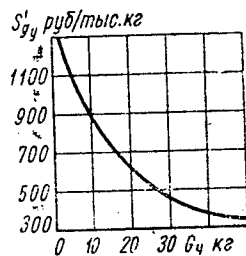


Figure 1.25. Relationship Between Specific Cost of Producing Shell Components of SCh 15-32 and SCh 18-36 Cast Iron and Weight (average outlays on materials 40%, average outlays on production worker wages 14% [3])

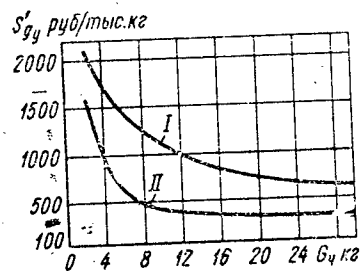


Figure 1.26. Relationship Between Specific Cost of Producing Spur Gears of Steel Forgings of 40Kh and 20Kh steel, Number of Units Produced and Weight [3] (average outlays on materials 39%; average outlays on production worker wages 16%): I -- series production up to 100 tons per year; II -- large-series production up to 500 tons per year

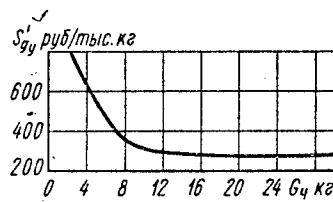


Figure 1.27. Relationship Between Specific Cost of Producing Spur Gears of SCh 15-32, SCh 18-36 and SCh 28-42 Cast Iron and Weight [3] (average outlays on materials 60%, average outlays on production worker wages 12%)

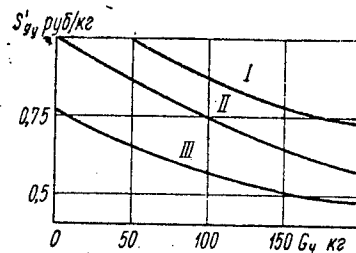


Figure 1.28. Relationship Between Specific Cost of Producing Gears and Type of Gear Blank and Weight: I -- cast steel; II -- forged and stamped; III -- cast iron

More precise calculations of production cost can be performed with formula (1.11) (see page 21) by means of preliminary determination of outlays on materials, semifinished products and purchased items, plus production worker wages, as well as the addition of indirect expenditures -- shop, general plant, and nonproduction.

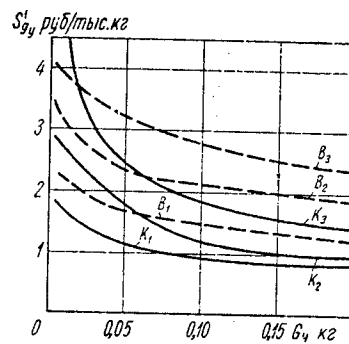


Figure 1.29. Relationship Between Specific Cost of Producing Plastic Parts and Their Weight [5]

Key to figure:  $K_1$  -- for simple parts of carbolite;  $B_1$  -- for simple parts of fiber-filled molding material;  $K_2$  -- for carbolite parts of average complexity;  $B_2$  -- for fiber-filled molding material parts of average complexity;  $K_3$  -- for complex carbolite parts;  $B_3$  -- for complex fiber-filled molding material parts

In order to find wages  $L$ , we must determine labor requirements  $T_d$  for parts manufactured, with the following formula:

$$T_d = t_{yd} G_n k_o \delta_m \text{ norm-hr/unit,} \quad (1.55)$$

where  $t_{yd}$  -- specific labor requirements in norm-hr/kg;  $G_n$  -- net weight of part, kg;  $k_o$  -- factor which takes into account part complexity;  $\delta_m$  -- production run factor (labor requirements).

Then we multiply the obtained value by the average wage rate, employing formula (1.8). Appendix 5 contains wage rates in machine building.

Calculation by the point method. Calculation of the cost of producing parts by the point method does not basically differ from an analogous calculation performed for complete items, assemblies and units. We must select several principal design parameters for the parts of a given class, determine the total points in conformity with the point system elaborated for it and, utilizing a value factor, calculate production cost taking into account corrections for the number of units to be produced in comparison with the conditions for which the curves were plotted. The most expedient procedure in employing this method for calculating the cost of producing parts is to prepare point graphs applicable to each type of production and to standard representatives of specific classes of parts (see Chapter 3). The range of parameters analyzed should not be large. For the pinion class, for example, with specified requirements on precision, the following parameters can be selected: pitch circle diameter (or outside diameter for bevel gears), number of teeth, net weight, number of machined surfaces (other than gear teeth).

For each parameter we plot the relationship of its magnitude and points. We obtain the value factor quantity on the basis of statistical studies, employing the plotted curves.

The cost of producing a designed gear for a given type of production is determined as follows: points are determined for each parameter, and then these points are added together and the sum value is multiplied by the value factor.

Table 1.16. Input Data for Automotive Bevel Gears, for Determining Value Factor

1 Ше- стерни	2 Чистый вес $G_n$ в кг	3 Число зубьев $z$	4 Число обраба- тываемых поверх- ностей $n$	5 Наружный диаметр $d_n$ в мм	6 Э бал- лов	7 Трудо- емкость $T$ в мин	6 $T/2$ бал- лов
А	11,4	22	15	180	6,37	220	35
Б	3,88	11	10	107	2,82	106	38
В	2,7	22	20	135	3,65	133	36,5

Key to table: 1 -- gears; 2 -- net weight in kg; 3 -- number of teeth; 4 -- number of machined surfaces; 5 -- outside diameter in mm, 6 -- points; 7 -- labor requirements  $T$ , in minutes

Table 1.16 contains as an example figures on automotive bevel gears produced in a quantity of 1,000-3,000 units per year. Employing the point system (Figure 1.30), we can calculate specific labor requirements per point. They are

$$\frac{35 + 38 + 36,5}{3} = 36,5.$$

Utilizing Figure 1.30 and the specific labor requirements index, we can determine the approximate labor requirements of designed bevel gears at a specified scale of manufacture. Cost of production is calculated with formula (1.11).

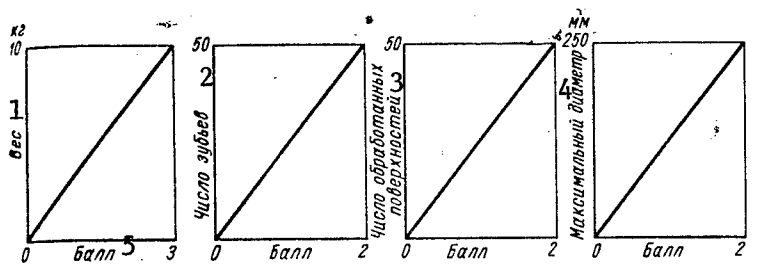


Figure 1.30. Point system for Calculating Bevel Gear Labor Requirements

Key to figure: 1 -- weight; 2 -- number of teeth; 3 -- number of machined surfaces; 4 -- maximum diameter; 5 -- points

Calculation based on correlations. Functional and correlational dependences are of considerable interest for calculating the cost of producing parts of various classes. The existence of such relations would make it possible at the detailed engineering stage to find the cost of producing parts, assemblies, units and items as a whole with an accuracy very closely approaching actual production cost.

However, at the present time we are familiar with only a few, unsystematized correlation formulas for calculating cost of production.

For example, in calculating the cost of producing gears with formula (1.11) under conditions of series production (annual production 300-1,000 units), the paired correlation formula was employed to determine outlays on materials:

$$M = (0,1G_n^{1,4} + 0,25)K, \quad (1,56)$$

where M -- outlays on basic materials, rub/unit;  $G_n$  -- net weight of part by drawings, kg; K -- coefficient which takes into account the difference in wholesale-release prices on materials (K=1 with a wholesale-release price per ton  $c_m=100$  rubles).

To calculate basic wages of production workers L, we employed an integral index which sums up individual paired relations [see formula (1.18)]:

$$L = \frac{S_{y1}l + S_{y2}d_z + S_{y3}z + S_{y4}G_n}{4} \text{ rub/unit, (1.57)}$$

where l -- gear length, including shanks, mm;  $d_z$  -- gear diameter on pitch circle (for bevel gears -- outside diameter), mm; z -- number of teeth;  $G_n$  -- net weight, kg;  $S_{y1}$  in rub/mm,  $S_{y2}$  in rub/mm,  $S_{y3}$  in rub/tooth,  $S_{y4}$  in rub/kg -- value specific indices (see Table 1.17).

Table 1.17. Value Specific Indices for Gears of Various Type

1 . Тип шестерен	$S_{y1}$ в руб/мм	$S_{y2}$ в руб/мм	$S_{y3}$ в руб/зуб	$S_{y4}$ в руб/кг
Цилиндрические: 2				
3 с внутренним зацеплением	0,060	0,012	0,06	0,40
4 с внешним зацеплением	0,025	0,012	0,06	0,40
5 Двухвенцовые . . . . .	0,040	0,012	0,11	0,40
6 Конические . . . . .	0,020	0,012	0,11	0,25

Key to table: 1 -- gear type; 2 -- spur; 3 -- with internal gearing; 4 -- with external gearing; 5 -- two-rimmed; 6 -- bevel

For steel shafts under the same conditions of manufacture, correlations will be expressed as follows:

$$M = (0,03G_n^2 + 0,2)K \text{ rub/unit} \quad (1.58)$$

$$L = 0,02G_n^2 + 0,5 \text{ rub/unit,} \quad (1.59)$$

for gray cast iron housing components

$$M = 0,05G_n + 0,25 \text{ rub/unit} \quad (1.60)$$

$$L = 0,55G_n^{0,75} \text{ rub/unit,} \quad (1.61)$$

for sheet steel covers (structural steel)

$$M = 0,64G_n \text{ rub/unit,} \quad (1.62)$$

of gray cast iron

$$M = 0,0675G_n \text{ rub/unit} \quad (1.63)$$

$$L = 0,175G_n + 0,3 \text{ rub/unit,} \quad (1.64)$$

for cast brackets, levers, housings of 40L steel

$$M = 0,0875G_u \text{ rub/unit} \quad (1.65)$$

$$L = 0,167G_u \text{ rub/unit.} \quad (1.66)$$

If M and L are known, the cost of producing a part can be calculated with the following formula:

$$S'_d = \left[ M + L \left( 1 + \frac{K_1 + K_2}{100} \right) + L \frac{\alpha}{100} \right] \times \\ \times \left( 1 + \frac{K_3}{100} \right) \text{ rub/unit,}$$

where  $K_1$ ,  $K_2$ ,  $K_3$  -- percentage of shop, general plant and nonproduction expenditures respectively.

Designers could be greatly assisted by formulas derived with the aid of multiple correlation methods. Such formulas not only make it possible to refine production cost calculations but also help in estimating the degree of influence of each of the evaluated parameters on production cost [see, for example, formula (1.41)]. Designers could more precisely determine which design parameters of parts of a given class exert decisive influence on the cost of manufacture and could devote greater attention to correct selection of these parameters.

Table 1.18. Input Data for Bevel Gear Parameters

1 Шестерни	2 Наружный диаметр $D_n$ в мм	3 Чистый вес $G_u$ в кг	4 Модуль $m$	5 Масштаб выпуска $N_{200}$	6 Трудоемкость $T_d$ в нормо-минутах/шт.
А	83	1,1	5	600	125
Б	80	0,5	6	3720	59
В	180	6,4	8	50	308
Г	460	29,8	12	25	1127
7 Сумма $\Sigma$	803	37,8	31	4395	1619
Среднее значение 8	$\bar{D}_n=201$	$\bar{G}_u=9,4$	$\bar{m}=8$	$\bar{N}_{200}=1099$	$\bar{T}_d=405$

Key to table: 1 -- gears; 2 -- outside diameter in mm; 3 -- net weight, kg; 4 -- modulus; 5 -- scale of production; 6 -- labor requirements in norm-minutes/unit; 7 -- sum; 8 -- average value

Table 1.19. Deviation of Bevel Gear Parameters from Average Values

I Шестерни	$D_k$		$G_u$		$m$		$N_{20\partial}$		$T$	
	$D_k - \bar{D}_k$	$(D_k - \bar{D}_k)^2$	$G_u - \bar{G}_u$	$(G_u - \bar{G}_u)^2$	$m - \bar{m}$	$(m - \bar{m})^2$	$N_{20\partial} - \bar{N}_{20\partial}$	$(N_{20\partial} - \bar{N}_{20\partial})^2$	$T - \bar{T}$	$(T - \bar{T})^2$
	I*		II		III		IV		V	
A	-118	13 924	-8,3	68,89	-3	9	-499	249 001	-280	78 900
B	-121	14 641	-8,9	79,21	-2	4	2621	6 869 641	-346	119 716
B	-21	441	-3,0	9,0	0	0	-1049	1 100 401	-97	9 409
F	259	67 081	20,4	416,16	4	16	-1074	1 153 476	722	521 284
$\Sigma$		96 087		537,26		29		9 372 519		728 809
$\Sigma/n$		24 022		143,3		7,25		2 343 130		82 202
$\sigma = \sqrt{\Sigma/n}$		155		11,9		2,69		1 531		427

\* Для облегчения дальнейших расчетов графы с данными, нужными для определения коэффициентов парной корреляции, обозначены римскими цифрами.

Key to table: I -- gears; \* -- in order to facilitate subsequent calculations, those columns with figures needed to determine paired correlation factors are designated by Roman numerals

Employment of the multiple correlation method will produce substantial effect.

Let us examine an example of constructing a correlation equation with a linear character of relation [of the type of formula (1.20)] on the basis of utilization of paired correlation factors. Input data on bevel gear parameters for determining the relationship between them and machining labor requirements with identical requirements pertaining to precision are contained in Table 1.18. Deviations from the average value of bevel gear parameters are contained in Table 1.19.

To find paired correlation factors we shall multiply the corresponding figures in the columns designated by Roman numerals, and we shall transfer the results to Table 1.20.

Table 1.20. Input Data for Finding Paired Correlation Factors

Шестерни Gears	I-II	I-III	I-IV	I-V	II-III
A	979,4	354	58 882	33 040	24,9
Б	1076,9	242	-317 141	41 866	17,8
В	63,0	0	22 029	2 037	0
Г	5283,6	1036	-278 166	186 998	81,6
Σ	7402,9	1632	-514 396	263 941	124,3

II-IV	II-V	III-IV	III-V	IV-V
4141,7	2324	1497	840	139 720
-23326,9	3079,4	-5242	692	-906 866
3147	291	0	0	101 753
-21909,6	14728,8	-4296	2888	-775 428
-37947,8	20423,2	-8041	4420	-144 082

According to equation (1.16), the paired correlation factor will be equal to

$$r_{ij} = \frac{\sum (\bar{y}_i - \bar{y}) \sum (\bar{x}_j - \bar{x})}{(\sum (\bar{y}_i - \bar{y})^2) (\sum (\bar{x}_j - \bar{x})^2)} = r_{x_j}$$

then, utilizing the values found in the tables, we shall obtain

$$\begin{aligned}
 r_{I, II} &= \frac{7402,9}{\sqrt{96\,087 \cdot 573,26}} = 0,997; \\
 r_{I, III} &= \frac{1632}{\sqrt{96\,087 \cdot 29}} = 0,978; \\
 r_{I, IV} &= \frac{-514\,396}{\sqrt{96\,087 \cdot 9\,372\,519}} = -0,542; \\
 r_{I, V} &= \frac{263\,941}{\sqrt{96\,087 \cdot 728\,809}} = 0,997; \\
 r_{II, III} &= \frac{124,3}{\sqrt{573,26 \cdot 29}} = 0,964; \\
 r_{II, IV} &= \frac{-37\,947,8}{\sqrt{573,26 \cdot 9\,372\,519}} = -0,518; \\
 r_{II, V} &= \frac{20423,2}{\sqrt{573,26 \cdot 728\,809}} = 0,999; \\
 r_{III, IV} &= \frac{-8041}{\sqrt{29 \cdot 9\,372\,519}} = -0,488; \\
 r_{III, V} &= \frac{4420}{\sqrt{29 \cdot 728\,809}} = 0,961; \\
 r_{IV, V} &= \frac{-1\,440\,821}{\sqrt{9\,372\,519 \cdot 728\,809}} = -0,551.
 \end{aligned}$$

We shall substitute the obtained paired correlation factor values in matrix (1.32):

$$\left. \begin{aligned}
 \beta_1 + 0,997\beta_2 + 0,978\beta_3 - 0,542\beta_4 &= 0,997; \\
 0,997\beta_1 + \beta_2 + 0,964\beta_3 - 0,518\beta_4 &= 0,999; \\
 0,978\beta_1 + 0,964\beta_2 + \beta_3 - 0,448\beta_4 &= 0,961; \\
 -0,542\beta_1 - 0,518\beta_2 - 0,488\beta_3 + \beta_4 &= -0,551.
 \end{aligned} \right\}$$

Below is a matrix solution for finding coefficients  $\beta$ . First we solve the system of equations for excluding parameters  $\beta_1$ :

$$\begin{aligned}
 &(1 - 0,997 \cdot 0,997) \beta_2 + (1 \cdot 0,964 - 0,997 \cdot 0,978) \beta_3 + \\
 &+ (-0,518 \cdot 1 + 0,997 \cdot 0,542) \beta_4 = 0,999 \cdot 1 - 0,997 \cdot 0,997; \\
 &(0,964 \cdot 1 - 0,978 \cdot 0,997) \beta_2 + (1 - 0,978 \cdot 0,978) \beta_3 + \\
 &+ (-0,488 \cdot 1 + 0,978 \cdot 0,542) \beta_4 = 0,961 \cdot 1 - 0,978 \cdot 0,997; \\
 &(-0,518 \cdot 1 + 0,542 \cdot 0,997) \beta_2 + (-0,488 \cdot 1 + 0,542 \times \\
 &\times 0,978) \beta_3 + (1 \cdot 1 - 0,542 \cdot 0,542) \beta_4 = -0,551 \cdot 1 + \\
 &+ 0,997 \cdot 0,542
 \end{aligned}$$

and we obtain a new system of three equations:

$$\left. \begin{aligned} 0,006\beta_2 - 0,011\beta_3 + 0,022\beta_4 &= 0,005; \\ -0,011\beta_2 + 0,044\beta_3 + 0,042\beta_4 &= -0,014; \\ 0,022\beta_2 + 0,042\beta_3 + 0,706\beta_4 &= -0,011, \end{aligned} \right\}$$

or, multiplying by 1,000,

$$\left. \begin{aligned} 6\beta_2 - 11\beta_3 + 22\beta_4 &= 5; \\ -11\beta_2 + 44\beta_3 + 42\beta_4 &= -14; \\ 22\beta_2 + 42\beta_3 + 706\beta_4 &= -11. \end{aligned} \right\}$$

Continuing calculation of matrix parameters, we eliminate parameter  $\beta_2$ :

$$\begin{aligned} (6 \cdot 44 - 11 \cdot 11) \beta_3 + (6 \cdot 42 + 11 \cdot 22) \beta_4 &= -6 \cdot 14 + 5 \cdot 11; \\ (6 \cdot 42 + 11 \cdot 22) \beta_3 + (6 \cdot 706 - 22 \cdot 22) \beta_4 &= -6 \cdot 11 - 5 \cdot 22 \end{aligned}$$

and we obtain a system of two equations:

$$\left. \begin{aligned} 143\beta_3 + 494\beta_4 &= -29; \\ 494\beta_3 + 3752\beta_4 &= -176. \end{aligned} \right\}$$

Its solution provides us with the following values of coefficients  $\beta_3$  and  $\beta_4$  of the equation in a standardized scale (1.33):

$$\begin{aligned} (143 \cdot 3752 - 494 \cdot 494) \beta_4 &= -143 \cdot 176 + 494 \cdot 29 \\ 292\,500\beta_4 &= -10\,842 \\ \beta_4 &= -0,037 \\ \beta_3 &= \frac{-176 - 3752\beta_4}{494} = -0,075. \end{aligned}$$

Then coefficients  $\beta_2$  and  $\beta_1$  respectively are equal to

$$\begin{aligned} \beta_2 &= \frac{5 + 11\beta_3 - 22\beta_4}{6} = \frac{5 - 0,825 + 0,814}{6} = 0,818; \\ \beta_1 &= 0,997 - 0,997\beta_2 - 0,978\beta_3 + 0,542\beta_4 = 0,997 - 0,815 + \\ &\quad + 0,073 - 0,02 = 0,235. \end{aligned}$$

The multiple correlation coefficient determined with equation (1.35),

$$r = \sqrt{\frac{0,997 \cdot 0,235 + 0,999 \cdot 0,818 + 0,961 (-0,075) + (-0,551) (-0,037)}{1}}$$

and equal to  $r=0.99$  -- is very high.

Transition from  $\beta$ -coefficients to parameters  $a_i$  is performed with a modulus [equation (1.34)]:

$$a_i = \beta_i \frac{\tau_v}{\sigma_i}.$$

In this case

$$T_{\partial} = a_0 + 0,235 \frac{427}{155} D_n + 0,818 \frac{427}{11,9} G_u - 0,075 \frac{427}{2,69} m - 0,037 \frac{427}{1531} N_{\partial\partial};$$

$$T_{\partial} = a_0 + (0,65D_n - 11,9m) + 29,3G_u - 0,01N_{\partial\partial}.$$

To find parameter  $a_0$  we substitute into the equation average values of input data from Table 1.18:

$$a_0 = 405 - (0,65 \cdot 201 - 11,9 \cdot 8) - 29,3 \cdot 9,4 + 0,01 \cdot 1099 = 405 - 36 - 276 + 11 = 104.$$

The formula we are seeking for determination of the labor requirements in the manufacture of bevel gears has the form

$$T_{\partial} = 104 + (0,65D_n - 11,9m) + 29,3G_u - 0,01N_{\text{year norm-min/unit.}} \quad (1.67)$$

Let us examine an example of obtaining a correlation formula for an exponential function between variable  $y$  (labor requirements for the manufacture of smooth shafts) and parameter-arguments  $x_1, x_2, x_3$  (net weight, scale of production, number of machined surfaces). The input data for our calculation are contained in Table 1.21.

Table 1.21. Input Data for Calculating Correlation Formula Parameters

1 Валы	2 Чистый вес $G_u$ в кг	3 Масштаб выпуска $N_{\partial\partial}$ в шт/год	4 Число обра- батываемых поверхностей $n_{об}$	5 Трудоемкость $T_{\partial}$ в нормоми- нутах/ шт.
Г	1,19	1845	20	244
Д	31,2	39	10	142
Е	1,3	278	15	83

Key to Table 1.21 on preceding page: 1 -- shafts; 2 -- net weight in kg; 3 -- scale of production, in units per year; 4 -- number of machined surfaces; 5 -- labor requirements in norm-minutes per unit

Input data matrix

$$\begin{pmatrix} 1,19 & 1845 & 20 & 244 \\ 31,2 & 39 & 10 & 142 \\ 1,3 & 278 & 15 & 83 \\ x_1 & x_2 & x_3 & y \end{pmatrix}$$

The equation we seek [see equation 1.37)] has the form

$$y = a_0 x_1^{b_1} x_2^{b_2} x_3^{b_3}$$

or after taking logarithms (see equation (1.38)):

$$\lg y = \lg a_0 + b_1 \lg x_1 + b_2 \lg x_2 + b_3 \lg x_3.$$

We shall designate  $\lg x_1 = u_1; \lg x_2 = u_2; \lg x_3 = u_3; \lg a_0 = a'_0;$

$\lg y = z$  and we obtain [see equation (1.39)]:

$$z = a'_0 + b_1 u_1 + b_2 u_2 + b_3 u_3.$$

By taking logarithms for each term in the above matrix, we obtain matrix

$$\begin{pmatrix} 0,0755 & 3,2660 & 1,3010 & 2,3874 \\ 1,4942 & 1,5911 & 1,0000 & 2,1523 \\ 0,1139 & 2,4440 & 1,1761 & 1,9191 \\ u_1 & u_2 & u_3 & z \end{pmatrix}$$

We determine unknowns  $a'_0, b_1, b_2, b_3$  with the aid of a Gram matrix [see equation (1.24)].

We shall find parameters  $a_{ij}$ :

$$a_{00} = \sum_1^N 1 = N = 4. \quad \text{-- number of equations;}$$

$$a_{01} = a_{10} = \sum u_1 = 0,0755 + 1,4942 + 0,1139 = 1,6836;$$

$$a_{02} = a_{20} = \sum u_2 = 3,2660 + 1,5911 + 2,4440 = 7,3011;$$

$$a_{03} = a_{30} = \sum u_3 = 1,3010 + 1,0000 + 1,1761 = 3,4771;$$

$$a_{11} = \sum u_1^2 = (0,0755)^2 + (1,4942)^2 + (0,1139)^2 = 0,00570 + 2,2300 + 0,0129 = 2,2486;$$

$$\begin{aligned}
a_{12} = a_{21} &= \sum u_1 u_2 = 0,0755 \cdot 3,2660 + 1,4942 \cdot 1,5911 + \\
&\quad + 0,1139 \cdot 2,444 = 2,906; \\
a_{13} = a_{31} &= \sum u_1 u_3 = 0,0755 \cdot 1,3010 + 1,4942 \cdot 1 + 0,1139 \times \\
&\quad \times 1,1761 = 1,7263; \\
a_{22} = \sum u_2^2 &= (3,2660)^2 + (1,5911)^2 + (2,4440)^2 = 10,65 + \\
&\quad + 2,53 + 5,97 = 19,15; \\
a_{23} = a_{32} &= \sum u_2 u_3 = 3,266 \cdot 1,301 + 1,5911 \cdot 1 + 2,444 \times \\
&\quad \times 1,1761 = 8,7111; \\
a_{33} = \sum u_3^2 &= (1,301)^2 + 1^2 + (1,1761)^2 = 1,69 + \\
&\quad + 1 + 1,38 = 4,07; \\
a_{0z} = \sum z &= 2,3874 + 2,1523 + 1,9191 = 6,4588; \\
a_{1z} = \sum u_1 z &= 0,0755 \cdot 2,3874 + 1,4942 \cdot 2,1523 + 0,1139 \times \\
&\quad \times 1,9191 = 3,611; \\
a_{2z} = \sum u_2 z &= 3,266 \cdot 2,3874 + 1,5911 \cdot 2,1523 + 2,444 \times \\
&\quad \times 1,9191 = 15,75; \\
a_{3z} = \sum u_3 z &= 1,301 \cdot 2,3874 + 1 \cdot 2,1523 + \\
&\quad + 1,1761 \cdot 1,9191 = 7,505.
\end{aligned}$$

We obtain a system of equations:

$$\left\{ \begin{aligned} 4a'_0 + 1,68b_1 + 7,30b_2 + 3,48b_3 &= 6,46; \\ 1,68a'_0 + 2,25b_1 + 2,91b_2 + 1,73b_3 &= 3,61; \\ 7,30a'_0 + 2,91b_1 + 19,15b_2 + 8,71b_3 &= 15,75; \\ 3,48a'_0 + 1,73b_1 + 8,71b_2 + 4,07b_3 &= 7,50, \end{aligned} \right\}$$

which we solve by the method of sequential elimination of unknowns:

$$\begin{aligned}
(1 \cdot 2,25 - 1,68 \cdot 0,42) b_1 + (1 \cdot 2,91 - 1,68 \cdot 1,82) b_2 + \\
+ (1 \cdot 1,73 - 1,68 \cdot 0,87) b_3 &= 1 \cdot 3,61 - 1,68 \cdot 1,61; \\
(1 \cdot 2,91 - 7,3 \cdot 0,42) b_1 + (1 \cdot 19,15 - 7,3 \cdot 1,82) b_2 + \\
+ (1 \cdot 8,71 - 7,3 \cdot 0,87) b_3 &= 1 \cdot 15,75 - 7,3 \cdot 1,61; \\
(1 \cdot 1,73 - 3,48 \cdot 0,42) b_1 + (1 \cdot 8,71 - 3,48 \cdot 1,82) b_2 + \\
+ (1 \cdot 4,07 - 3,48 \cdot 0,87) b_3 &= 1 \cdot 7,5 - 3,48 \cdot 1,61; \\
\left\{ \begin{aligned} b_1 + 0,097 b_2 + 0,176 b_3 &= 0,586; \\ -0,155 b_1 + 5,87 b_2 + 2,36 b_3 &= 4; \\ 0,27 b_1 + 2,38 b_2 + 1,04 b_3 &= 1,9; \end{aligned} \right\}
\end{aligned}$$

$$\begin{aligned}
(1.5,87 + 0,155 \cdot 0,097) b_2 + (1.2,3 + 0,155 \cdot 0,176) b_3 &= \\
&= 1.4 + 0,155 \cdot 0,586; \\
(1.2,38 - 0,27 \cdot 0,097) b_2 + (1.1,04 - 0,27 \cdot 0,176) b_3 &= \\
&= 1.1,9 - 0,27 \cdot 0,586; \\
\begin{cases} b_2 + 0,406 b_3 = 0,696; \\ 2,354 b_2 + 0,993 b_3 = 1,742; \end{cases} \\
(1.0,993 - 2,354 \cdot 0,406) b_3 = 1.1,742 - 2,354 \cdot 0,696; \\
b_3 = \frac{0,103}{0,038} = 2,71; \\
b_2 = 0,696 - 0,406 \cdot 2,71 = 0,696 - 1,1 = -0,404; \\
b_1 = 0,586 - 2,71 \cdot 0,176 + 0,097 \cdot 0,404 = 0,146; \\
a'_0 = 1,61 - 0,146 \cdot 0,42 + 0,404 \cdot 1,82 - 2,71 \cdot 0,87 = \\
= -0,071.
\end{aligned}$$

We obtain equation

$$z = -0,071 + 0,146 u_1 - 0,404 u_2 + 2,71 u_3;$$

after taking antilogarithms, the desired formula assumes the following form:

$$y = 0,8492 x_1^{0,146} x_2^{-0,404} x_3^{2,71}$$

or

$$T_0 = 0,8492 G_q^{0,146} N_{zod}^{-0,404} h_{od}^{2,71} \quad \text{norm-minutes/unit} \quad (1.68)$$

Influence of precision of machining, surface finish and scale of production on cost of production. The cost of producing parts is greatly influenced by the required precision and surface finish, which is desirable to take into consideration when deriving a correlation formula. Figure 1.31 [1] shows the relationship between cost of machining on the one hand and surface finish and tolerances on the other (according to the figures of the Warner and Swasy Company), while Figure 1.32 shows the relationship between the cost of an operation and machining precision according to the figures of S. A. Tilles; Figure 1.33 shows the relationship between machining costs and precision of manufacture [7].

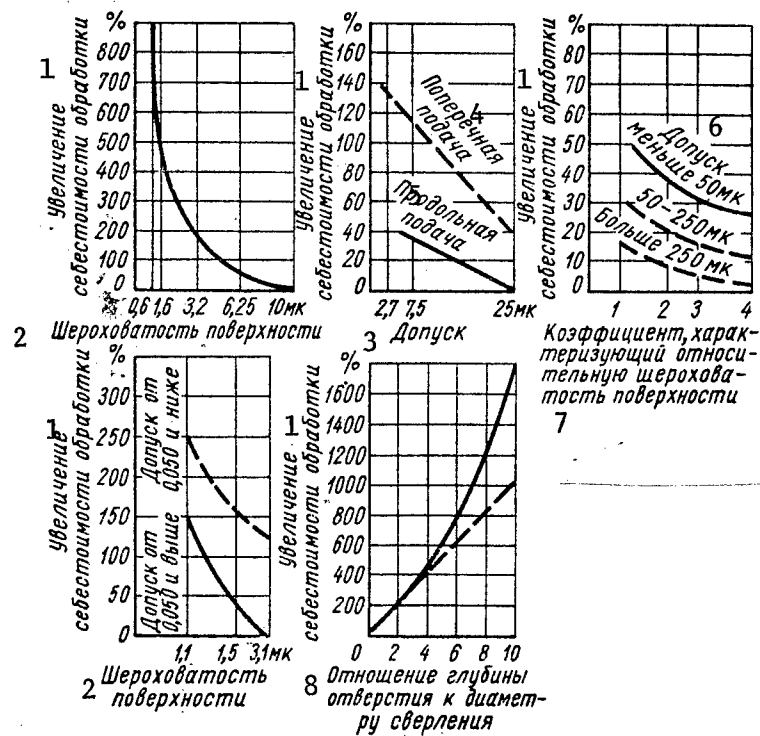


Figure 1.31. Relationship Between Cost of Machining, Surface Finish and Tolerances

Key to figure: 1 -- increase in cost of machining; 2 -- surface roughness; 3 -- tolerance; 4 -- transverse feed; 5 -- longitudinal feed; 6 -- tolerance less than; 7 -- factor characterizing relative surface roughness; 8 -- ratio of hole depth to drill diameter

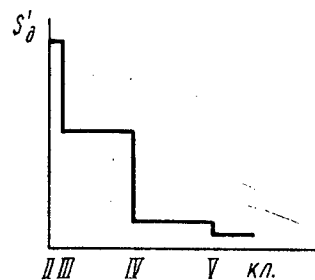


Figure 1.32. Relationship Between Cost of Producing a Part and Machining Precision

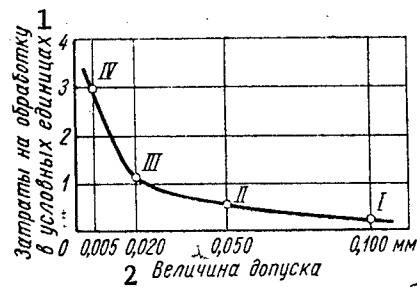


Figure 1.33. Relationship Between Cost of Machining and Precision of Manufacture

Key to figure: 1 -- expenditures on machining in standard units; 2 -- tolerance; I -- machining a hole: drill, shaft-cold drawn rod; II -- machining a hole: drill, deburring, ream: shaft machining: grinding; III -- machining a hole: drill, grind; machine shaft: grind; IV -- machining a hole: drill, grind, finish; machining a shaft, turn, grind, finish

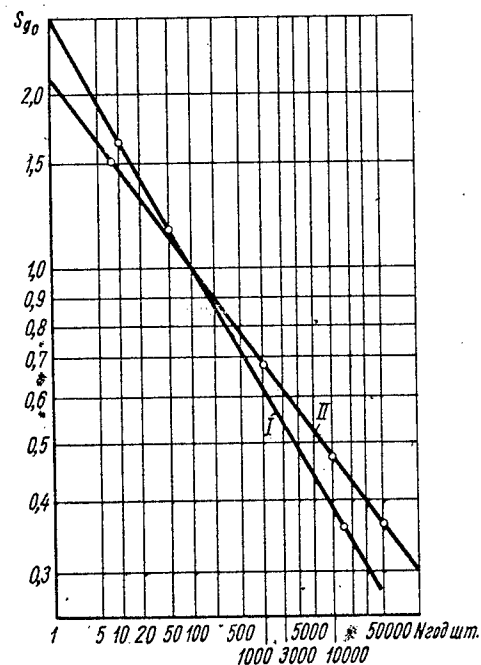


Figure 1.34. Relationship Between Relative Cost of Producing Parts, the Scale of Their Production and Weight

Key to figure: I -- parts with average weight of 0.25 kg; II -- parts with average weight of 100 kg

The question of the influence of scale of production on production cost has been examined in detail above. Here we are merely concretizing the given relationship as applied to various types of parts. Figure 1.34 [7] shows the relationship between relative production cost, the weight of parts and the scale of their production. Tables 1.22, 1.23 and 1.24 [5] contain approximate figures on production run factors based on production cost  $\delta$ , labor requirements  $\delta_t$ , and basic materials  $\delta_m$ , which can be utilized to correct corresponding quantities in scale of production.

Table 1.22. Production Run Factor  $\delta$  Values (for cost of producing parts)

1 Детали и полуфабрикаты	2 Отношение предполагаемого годового выпуска проектируемой детали к годовому выпуску освоенных деталей $N_{год}/N_{год_0}$											3 Исследованные пределы годовой программы $N_{год}$
	2	3	5	7	10	20	50	100	200	500	1000	
4 Отливки из серого чугуна	0,93	0,89	0,85	0,81	0,78	0,72	0,65	0,60	0,56	0,50	0,46	До 100 000 шт » 60 000 »
5 Поковки . . . . .	0,95	0,93	0,90	0,87	0,85	0,81	0,76	0,72	0,69	0,65	0,62	
6 Штамповки из углеродистой (а), легированной (б) сталей . . . . .	0,93	0,90	0,85	0,82	0,80	0,71	0,68	0,63	0,59	0,54	0,50	20 000 » (а) » 150 000 » (б)
7 Шестерни цилиндрические до 2 кг . . . . .	0,92	0,88	0,82	0,79	0,76	0,70	—	—	—	—	—	10—300 000 кг
8 Шестерни стальные до 20 кг . . . . .	0,84	0,76	0,67	0,61	0,56	0,47	0,38	—	—	—	—	10—300 000 »
9 Звездочки для цепей стальные до 1 кг . . . . .	0,89	0,82	0,75	0,71	0,66	0,58	0,50	—	—	—	—	20—500 000 шт.
10 Звездочки для цепей стальные до 5 кг . . . . .	0,96	0,94	0,91	0,89	0,87	0,84	0,79	—	—	—	—	20—500 000 »
11 Втулки до 1 кг . . . . .	0,91	0,87	0,81	0,78	0,74	0,68	0,60	—	—	—	—	—
12 Втулки бронзовые до 10 кг . . . . .	0,97	0,95	0,92	0,91	0,89	0,86	0,82	—	—	—	—	—
13 Валы из прутков до 30 кг . . . . .	0,85	0,77	0,68	0,63	0,58	0,48	0,39	—	—	—	—	—
14 Болты с гайками черные	0,89	0,82	0,75	0,71	0,66	0,58	0,50	0,44	0,39	0,33	0,29	—

Key to Table 1.22 on preceding page: 1 -- parts and semimanufactures; 2 -- ratio of proposed annual output volume of newly-designed part to output volume of currently-manufactured parts; 3 -- investigated limits of annual production schedule; 4 -- gray iron castings; 5 -- forgings; 6 -- stampings of carbon (a) and alloy (b) steels; 7 -- spur gears to 2 kg; 8 -- steel gears to 20 kg; 9 -- steel sprocket wheels to 1 kg; 10 -- steel sprocket wheels to 5 kg; 11 -- bushings to 1 kg; 12 -- bronze bushings to 10 kg; 13 -- shafts from rods to 30 kg; 14 -- ferrous bolts with nuts

Table 1.23 Production Run Factor  $\delta_m$  Values (for parts labor requirements)

1 Детали и полуфабрикаты	2 Отношение предполагаемого годового выпуска проектируемой детали к годовому выпуску освоенных деталей $N_{год,н}/N_{год,с}$											3 Исследованные пределы годовой программы $N_{год}$
	2	3	5	7	10	20	50	100	200	500	1000	
4 Отливки из серого чугуна	0,91	0,86	0,80	0,76	0,72	0,66	0,58	0,52	0,48	0,42	0,38	До 100 000 шт.
Поковки 5	0,85	0,77	0,68	0,63	0,58	0,48	0,39	0,33	0,28	0,23	0,19	» 60 000 »
Штамповки из углеродистой стали 6	0,85	0,77	0,68	0,63	0,58	0,48	0,39	0,33	0,28	0,23	0,19	» 20 000 »
Штамповки из легированной стали 7	0,74	0,62	0,50	0,43	0,37	0,28	0,19	0,14	0,10	0,07	0,05	» 150 000 »
Шестерни цилиндрические до 2 кг 8	0,76	0,66	0,53	0,46	0,40	0,30	—	—	—	—	—	10—300 000 шт.
Шестерни цилиндрические стальные до 20 кг 9	0,52	0,35	0,22	0,16	0,11	0,06	—	—	—	—	—	10—300 000 шт.
Звездочки для цепей из стали 45 до 1 кг 10	0,66	0,52	0,33	0,31	0,25	0,17	—	—	—	—	—	20 000—500 000 шт.
Звездочки из стали 45 до 5 кг 11	0,76	0,65	0,53	0,46	0,40	0,30	—	—	—	—	—	20 000—500 000 шт.
Шкивы клиноременные до 5 кг 12	0,71	0,58	0,45	0,38	0,32	0,22	—	—	—	—	—	1—100 000 шт.
Шкивы клиноременные чугунные до 40 кг 13	0,79	0,69	0,58	0,52	0,46	0,36	0,23	0,21	0,17	0,12	0,10	1—100 000 »

Key to Table 1.23 on preceding page: 1-5 -- see key to Table 1.22; 6 -- carbon steel stampings; 7 -- alloy steel stampings; 8 -- spur gears to 2 kg; 9 -- steel spur gears to 20 kg; 10 -- sprocket wheels of 45 steel to 1 kg; 11 -- sprocket wheels of 45 steel to 5 kg; 12 -- vee-belt pulleys to 5 kg; 13 -- cast iron vee-belt pulleys to 40 kg

Table 1.24. Production Run Factor  $\delta_m$  Values (for basic materials of parts)

1 Детали	2 Отношение предполагаемого годового выпуска проекти- руемой детали к годовому выпуску обычных деталей $N_{год_H} / N_{год_C}$						3 Исследован- ные пределы годовой программы $N_{год}$
	2	3	5	7	10	20	
4 Шестерни цилиндриче- ские стальные до 0,2 кг	0,93	0,90	0,85	0,82	0,80	0,74	10—300 000 шт.
5 Звездочки для цепей из стали 45 до 1 кг . .	0,89	0,82	0,75	0,71	0,66	0,58	20—500 000 шт.
6 Звездочки для цепей из стали 45 до 5 кг . .	0,95	0,92	0,88	0,85	0,83	0,79	20—500 000 шт.
7 Шкивы клиноременные чугунные от 5 до 40 кг	0,97	0,95	0,92	0,91	0,89	0,86	1—100 000 шт.

Key to table: 1-3 -- see key to Table 1.22; 4 -- steel spur gears to 0.2 kg; 5 -- sprocket wheels of 45 steel, to 1 kg; 6 -- sprocket wheels of 45 steel, to 5 kg; 7 -- cast iron vee-belt pulleys, 5 to 40 kg

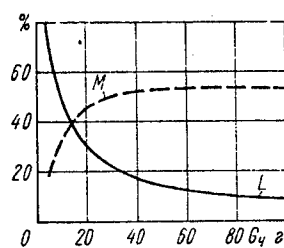


Figure 1.35. Relationship Between Percentage Share of Outlays on Materials M and Production Worker Wages L on the One Hand and Weight of Plastic Parts on the Other

Figure 1.35 contains an example of change in the structure of the production cost of plastic parts [5] in relation to their weight.

It is particularly important to know the production cost structure of parts of similar designs in those cases where the percentage share of outlays on materials is fairly high. Then one can employ formula (1.54) without major errors in the accuracy of calculations. As already noted, it is significantly simpler to determine outlays on materials at the given stage of the design process than to calculate labor requirements and wages.

Transition at the detailed engineering stage to part-by-part relations for complex units and assemblies possessing a high degree of innovation makes it possible to bring the accuracy of production cost calculations almost up to the accuracy of planning calculations performed in the process of preproduction engineering.

On the whole one can assume that certain methods of calculating production cost, particularly correlation analysis methods, ensure fully sufficient accuracy for subsequent analysis of the technical-economic effectiveness of the newly-designed machinery item at the preproduction design stage.

## CHAPTER 2.

### PRODUCTION COST CALCULATIONS DURING PREPRODUCTION ENGINEERING

#### 1. Methods of Determining Production Cost

Preproduction engineering is effected in several stages performed in sequence or parallel-sequence. In general these stages include the following: elaboration of manufacturing process routing and operation-by-operation manufacturing processes, design and fabrication of process equipment, its testing and adjustment, and turning over manufacturing processes to production shops. The composition and degree of elaboration detail for each stage of preproduction engineering are determined in large measure by the type of production. For example, under conditions of single-unit production the principal and sometimes only stage may be the elaboration of process routing.

As individual stages are completed, an increasing volume of information is collected on the parameters of the new machinery item, particularly manufacturing process indices (manufacturing process equipment factors, employed equipment and accessory support, machining conditions, etc); organizational indices (level of production flow, level of work station specialization and procedure of work station operation and support), etc (see Figure 3).

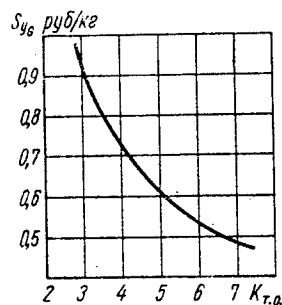


Figure 2.1. Relationship Between Specific Production Cost of Lathes and Process Equipment Factor

This volume of information makes it possible to perform plan-specified calculations on machinery production cost with a high degree of accuracy (Table 2.1). At the first stage of preproduction engineering one can effect further refinement of previously-performed calculations by the methods discussed in Chapter 1. In series and mass production one can calculate planned production cost by methods based on the appropriate instructions of USSR Gosplan [8] only after establishing at the second and third stages of preproduction engineering standard figures on the various types of outlays contained in production cost.

Table 2.1. Methods of Determining Production Cost at Different Stages of Preproduction Engineering

Этап 1	Состав основных работ 2	3 Примерный перечень параметров, влияющих на себестоимость и известных на данном этапе	4 Способ расчета себестоимости
5 Разработка маршрутной технологии	6 Уточнение принципиальной схемы сборки изделия; составление спецификации марок и профилей материалов; разработка укрупненных нормативов расхода материалов и трудоемкости; уточнение спецификации покупных заготовок, деталей, узлов, агрегатов и разработка технических условий; установление маршрутов движения деталей и определение ориентировочного объема работ по цехам; составление подетальной спецификации по каждому цеху; предварительное определение коэффициентов оснащенности технологических процессов	7 Параметры, известные из конструкторской подготовки производства (см. табл. 1.1), а также уточненный перечень кооперированных поставок; укрупненные нормативы расхода материалов; укрупненные нормативы трудоемкости; коэффициенты оснащенности технологических процессов и др.	8 Уточненные расчеты методами, рассмотренными в гл. 1: метод удельных показателей, метод баллов, метод корреляционных зависимостей
9 Разработка детальных технологических процессов	10 Составление технических условий и технологических чертежей на заготовки;	11 То же, а также нормы расхода материалов, нормы времени, нормы расхода технологической энергии и топлива, инструментов и т. д.	12 Предварительная калькуляция плановой себестоимости машины обычным способом
	разработка подетальных или подетально-пооперационных и сборочных технологических процессов; расчет норм расхода материалов, времени и др.; разработка методов контроля качества		

(Table cont'd on next page)

Table 2.1 (cont'd)

13 Проектирование и изготовление оснастки	14 Составление технического задания на проектирование оснастки; проектирование технологического оснащения; уточненный расчет технических норм времени или выработки, норм расхода материалов, топлива, энергии, инструментов, составление сводных норм трудоемкости по цехам и видам работ; расчеты загрузки оборудования и рабочих мест; составление норм применяемости материалов, инструментальных карт, спецификаций инструментов и дополнительного оборудования и т. д.; планировка оборудования на производственных участках	15 Уточненные нормы расхода материалов, времени или выработки, расхода технологической энергии и топлива, инструментов, амортизации оборудования и приспособлений, расходов на обслуживание и ремонт и т. д.	16 Уточненная плановая калькуляция себестоимости машины обычным способом
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Key to table: 1 -- stage; 2 -- composition of principal operations; 3 -- approximate list of parameters influencing production cost and known at the given stage; 4 -- method of calculating production cost; 5 -- elaboration of process routing; 6 -- refinement of item assembly arrangement; determination of specification of materials, grades and shapes; elaboration of consolidated standard figures on materials expenditures and labor requirements; refinement of specification of purchased workpieces, parts, assemblies, units and elaboration of specifications; establishment of parts routing and determination of the approximate work volume for each shop involved; preparation of part-by-part specification for each shop; preliminary determination of manufacturing process equipment factors; 7 -- parameters known from preproduction design (see Table 1.1), as well as a refined list of cooperative-manufacture items; consolidated standard figures on expenditure of materials; consolidated standard figures on labor requirements; manufacturing process equipment factors, etc; 8 -- refined calculations by the methods discussed in Chapter 1; method of specific indices, point method, correlation method; 9 -- elaboration of detailed manufacturing processes; 10 -- determination of specifications and process drawings for castings, forgings, etc; elaboration of part-by-part or part-by-part and operation-by-operation and assembly processes; calculation of standard figures on expenditure of materials, time, etc; elaboration of quality control methods; 11 -- same, as well as standard figures on expenditure of materials, standard figures on time, expenditure of process power and fuel, tools, etc; 12 -- preliminary costing of plan-specified machinery item production cost, by conventional method; 13 -- design and manufacture of tooling; 14 -- tooling preliminary design; designing process equipment; refined calculation of standard time or output figures, standard figures for expenditure of materials, fuel, power, tools, preparation of summary standard labor requirements for shops and types of operations; calculations of equipment and work station work loading; preparation of

(Key to Table 2.1 continued from preceding page) standard figures for applicability of materials, tool charts, specifications on tools and supplementary equipment, etc; production section equipment planning; 15 -- refined standard figures on expenditure of materials, time or output, consumption of process energy and fuel, tools, depreciation on equipment and accessories, outlays on servicing and maintenance, etc; 16 -- refined plan costing of machinery item production cost, by normal method

At the first stage of preproduction engineering for series or mass production one can figure in with considerably greater accuracy the influence on production cost of such indicators, for example, as process equipment. We know that equipping a process with special tools, dies and accessories is determined in large measure by the type of production (Table 2.2). It is also determined by the complexity of the parts being manufactured, their degree of precision and interchangeability. As production figures grow, process equipment also grows, with simple general-purpose equipment replaced by more complex and expensive special equipment.

Table 2.2. Equipment Factors for Various Branches of Machine Building and Types of Production

1 Вид оснастки	2 Тип производства							
	3 Единичное	4 Мелкосерийное	5 Серийное	6 Крупносерийное		7 Массовое		
	8 Станкостроение	8 Станкостроение	8 Станкостроение	8 Станкостроение	9 Сельхозмашиностроение	9 Сельхозмашиностроение	10 Грузовое автостроение	11 Тракторостроение
12 Литейная оснастка в комплектах	0,05	0,06	0,07	0,07	0,01—0,03	0,01—0,03	0,08	0,21
13 Штампы и пресформы в комплектах . . . . .	—	—	0,1—0,15	0,4—0,5	0,6—0,7	0,8—0,9	1,02	0,72
14 Приспособления для механической обработки в шт. . . . .	0,08	0,2—0,3	0,5—1,0	1,5—2,0	0,4—0,5	0,4—0,6	1,8	1,75
15 Специальный режущий инструмент в шт. . . . .	0,04—0,08	0,15—0,25	0,3—0,5	0,6—0,8	0,1—0,2	0,2—0,3	3,0	2,7
16 Специальный мерительный инструмент в шт. . . . .	0,09—0,2	0,2—0,35	0,4—0,8	1,0—1,4	0,8—2,0	2,6—2,8	3,8	6,2
17 Прочие виды оснастки в шт. . . . .	0,03	0,07—0,1	0,15—0,2	0,4—0,6	0,3	0,4—0,6	0,8	0,9
18 Общий (средний) коэффициент оснащенности . . . . .	0,3	0,75	2,2	5,2	2,21—3,73	4,41—5,13	10,5	12,48

Key to table: 1 -- type of equipment; 2 -- type of production; 3 -- single-unit; 4 -- small-series; 5 -- series; 6 -- large-series; 7 -- mass; 8 -- machine tools; 9 -- agricultural machine building; 10 -- truck manufacture; 11 -- tractor manufacture; 12 -- foundry equipment in sets; 13 -- dies and die-casting molds in sets; 14 -- devices and fixtures for machining, units;

(Key to Table 2.2 continued from preceding page) 15 -- special cutting tools, units; 16 -- special measuring devices, units; 17 -- other types of equipment, units; 18 -- overall (average) equipment factor

Ensuring high labor productivity, the latter, in spite of high one-time expenditures on its manufacture or purchase, reduces the cost of the items produced. Labor productivity increase, for example, leads to a decrease in the percentage share of wages in production cost, while mass production diminishes the share of depreciation allowance and other outlays per unit of output.

Figure 2.1 indicates the relationship between the specific cost of producing lathes and the equipment factor [12], defined as the ratio of the number of special equipment item designations to the number of item designations of unique item components.

A decrease in machining labor requirements with an increase in the equipment factor is characterized by the following figures:

Process equipment factor	0	0.5	1.0	1.5	2.0	2.5	3.0
Relative labor requirements of parts machining per ton of machinery item weight	1.80	1.00	0.60	0.40	0.28	0.20	0.10

The inclusion of such indices, in a point evaluation system or correlation formula, for example, can refine the production cost figures calculated in the process of preproduction design. We present below several correlation formulas which can be utilized at this stage for calculating machinery production cost. These formulas also include several process parameters.

For gang tools, for example, in designing unique assemblies, machining labor requirements can be obtained with the following correlation formula [16]:

$$T_{op} = 0,4835 m^{0,2324} F^{0,3968} n^{0,2962} \quad \text{norm-hours/unit,} \quad (2.1)$$

where  $m$  -- number of machining operations for all parts of machine tool unique assemblies;  $F$  -- number of machined surfaces (or in-process moves);  $n$  -- number of parts in unique machine tool assemblies.

Labor requirements of gang tool clamping fixtures

$$T_n = 0,31 m_n^{0,7786} G_n^{0,0576} n_n^{0,2486} \quad \text{norm-hours/unit,} \quad (2.2)$$

where  $m_n$  -- number of process operations (machining) for all parts of a unique part of a clamping device;  $G_n$  -- weight of device, kg;  $n_n$  -- number of parts contained in unique part of device.

The labor requirements of manufacturing parts of gang tools, in relation to weight, number of operations and number of machined surfaces:

$$T_d = 0,160 G_d^{0,146} m_d^{0,227} F_d^{0,783} \quad \text{norm-hours/unit,} \quad (2.3)$$

where  $G_d$  -- weight of part, kg;  $m_d$  -- number of machining operations;  $F_d$  -- number of machined surfaces (or in-process moves).

In many cases one can employ to calculate production cost or labor requirements at this stage refined formulas which take into account the parameters of the equipment used in manufacturing these parts. We offer as an example formula (2.4) for calculating the labor requirements in producing parts of plastics [5]:

$$T_d = \frac{G_d}{60 Q k_Q} \tau_0 k_d (1 + \varepsilon) \quad \text{norm-hours/unit,} \quad (2.4)$$

where  $G_d$  -- weight of part, in grams;  $\tau_0$  -- average duration of casting cycle (depends on type of equipment: the greater the maximum weight of casting permitted by the equipment, the greater quantity  $\tau_0$ ), in minutes;  $k_d$  -- parts complexity factor;  $\varepsilon$  -- factor (ratio of labor requirements for trimming part to labor requirements of molding);  $Q$  -- equipment power, tons;  $k_Q$  -- equipment power utilization factor.

## 2. Costing Machinery Plan-Specified Production Cost

In the process of performing additional production preengineering activities, following elaboration of detailed manufacturing processes and equipment design, the volume of known information on the new machinery item increases sharply. Precise standard figures on expenditure of all materials, standard figures on time (or output), expenditure of process energy, tools, etc become known. This makes it possible to effect planned determination of the cost of producing the new machinery item and to make a final verification of the correctness of the prior-performed analysis of technical-economic effectiveness.

Classification of production outlays. For purposes of planning production cost, all production outlays are divided on the basis of the following main features: by costing items, by expenditure elements, by the method of including in cost of production, and by degree of dependence on production volume.

Costing items are used to differentiate outlays on basic materials; purchased component items, semimanufactures and the services of cooperative manufacture enterprises; recoverable waste (subtracted); fuel for process purposes<sup>1</sup>; power for process uses; basic wages of production workers; production worker supplementary wages; social insurance contributions, as a percentage of production worker wages; putting new products into production (for enterprises lacking a new equipment setup fund); amortization on tool wear and special-purpose devices, plus other special expenditures; equipment servicing and maintenance, as well as shop, general plant and non-production expenditures.

On the basis of expenditure elements we must distinguish: material outlays [outlays on basic materials, semimanufactures, and component items (minus recoverable waste)], auxiliary materials, fuel, electric power, steam, compressed air, etc obtained from outside sources; enterprise employee basic and supplementary wages; social insurance contributions; depreciation on fixed assets; cash outlays (administrative, management, etc).

With the production cost inclusion method, outlays are broken down into direct and indirect.

Direct outlays are determined on the basis of direct count, since they can be established on the basis of existing standard amounts per unit of output, such as standard labor requirements (basic worker wages), standard consumption of basic materials (outlays on basic materials). It is desirable to apply as large a portion of production outlays as possible to the cost of producing individual items by direct attribute.

Indirect outlays in production costing are figured conditionally (on the basis of estimated rates, proportional to wages, etc), since they cannot be applied directly to a given specific item. They include, for example, expenditures on shop lighting and heating, wages of engineer-technician personnel, etc.

By degree of dependence on production volume expenditures are divided into standard-variable (proportional) and standard-constant.

The sum of standard-variable (proportional) expenditures for a year, quarter or other period changes -- increases or decreases -- proportional to product output volume (for example, production worker wages when paid on a piece-rate system, cost of basic materials).

The sum of standard-constant expenditures (annual, quarterly, etc) does not change or changes insignificantly with a change in production volume (for example, expenditures on shop heating, lighting, cleaning, etc, wages of shop supervisory personnel and plant administration and management, etc). Therefore with an increase in output their percentage share per item decreases. There is also a corresponding decrease in machinery production cost. On the other hand, with target nonfulfillment production cost increases in view of an increase in the share of standard-constant outlays in the cost of producing a unit of product.

Figure 2.2 contains a layout of the forming of production cost and product wholesale-release price, while Table 2.3 contains an approximate distribution of expenditures in different branches.

1      Оптово-отпускная цена предприятия					
2      Плановая себестоимость					
3      Заводская себестоимость			8      Вне- произ- вод- ствен- ные затра- ты	9      При- быль пред- прия- тия	
4      Цеховая себестоимость		7      Обще- завод- ские затра- ты			
5      Прямые затраты					6      Цеховые косвенные затраты
Затраты на основные ма- териалы, полу- фабрикаты, комплектую- щую продук- цию 19					
Затраты на основную за- работную пла- ту основных производствен- ных рабочих		Пропор- циональ- ные	Условно-постоян- ные		13
		12			

Figure 2.2. Forming of Production Cost and Wholesale-Release Price

Key to figure: 1 -- enterprise wholesale-release price; 2 -- plan-specified production cost; 3 -- plant cost; 4 -- shop cost; 5 -- direct outlays; 6 -- shop indirect expenditures; 7 -- general plant expenditures; 8 -- nonproduction expenditures; 9 -- enterprise profit; 10 -- outlays on basic materials, semimanufactures, component items; 11 -- outlays on basic wages of basic production workers; 12 -- proportional; 13 -- standard-constant

Table 2.3. Approximate Distribution of Outlays in Various Branches of Industry, %

1 Отрасль	2 Затраты		
	3 Материалы, полуфабрикаты, комплектующие изделия	4 Заработная плата основных производственных рабочих	5 Косвенные
6 Тяжелое машиностроение . . . . .	50	10	40
7 Станкостроение . . . . .	60	15	25
8 Сельскохозяйственное машиностроение . . . . .	57	9	34
9 Автомобилестроение . . . . .	55	10	35
10 Угольное машиностроение . . . . .	50	24	26
11 Инструментальная промышленность . . . . .	55	12	33
12 Продовольственное машиностроение . . . . .	54	15	31
13 Текстильное машиностроение . . . . .	48	19	33
14 Гидромашиностроение . . . . .	50	13	37
15 Строительно-дорожное машиностроение . . . . .	52	12	36
16 Электротехническая и приборостроительная промышленность . . . . .	75	7	18

Key to Table 2.3 on preceding page: 1 -- branch; 2 -- outlays; 3 -- materials, semimanufactures, component items; 4 -- wages of basic production workers; 5 -- indirect; 6 -- heavy machinery; 7 -- machine tools; 8 -- agricultural equipment; 9 -- automotive; 10 -- coal mining equipment; 11 -- tool industry; 12 -- food-processing equipment; 13 -- textile machinery; 14 -- hydraulic engineering; 15 -- heavy construction equipment; 16 -- electrical equipment and instrument engineering

Preparing estimates. The first stage in plan costing is the preparation of estimates -- of shop, general plant and nonproduction outlays, and expenditures on putting new products into production.

The shop expenditures estimate includes expenditures on equipment operation and maintenance (Table 2.4), as well as expenditures on shop personnel, buildings, other structures, and miscellaneous equipment maintenance, minor repairs on buildings and other structures, depreciation on buildings, other structures and miscellaneous equipment, expenditures on research, development and testing, on efficiency innovation and invention activities, on industrial safety, on amortization of wear and tear on low-cost and rapid-wear miscellaneous equipment, etc.

Table 2.4. Estimate of Expenditures on Operation and Maintenance of Machine Shop Equipment

1	Статьи затрат	2 Сумма в тыс. руб.
3	а. Содержание оборудования и других рабочих мест	
4	Материалы для технологических и производственных целей . . . . .	127,4
5	Топливо и энергия всех видов на производственные цели . . . . .	160,0
6	Заработная плата рабочих, обслуживающих производственное оборудование и рабочие места . . . . .	331,1
		618,5
7	б. Текущий ремонт производственного оборудования, транспортных средств и ценных инструментов:	
8	Текущий ремонт . . . . .	90,7
9	Другие расходы и услуги . . . . .	62,0
		152,7
10	в. Эксплуатация транспорта . . . . .	21,7
11	г. Амортизация производственного оборудования и транспортных средств . . . . .	327,7
12	д. Возмещение износа малоценных и быстроизнашивающихся инструментов . . . . .	225,2
13	Итого . . . . .	1345,8

Key to table: 1 -- expenditure items; 2 -- sum, thousand rubles; 3 -- maintenance of equipment and other work stations; 4 -- materials for process and production requirements; 5 -- fuel and energy of all types for production

(Key to Table 2.4, cont'd) needs; 6 -- wages of workers operating production equipment and work stations; 7 -- minor repairs on production equipment, transfer and transport equipment, and expensive tools; 8 -- minor repairs; 9 -- other expenditures and services; 10 -- transport operation; 11 -- depreciation of production equipment and means of transportation, transfer devices; 12 -- amortization of wear on miscellaneous and rapid-wear tools; 13 -- total

---

For comparison of estimates one utilizes figures on shop production schedule, including new items to be produced in the plan-covered year, standard consumption figures on auxiliary materials, fuel, power, standard depreciation allowance, payroll on auxiliary workers, engineers, technicians, white-collar workers, etc. For example, expenditures on maintenance of production equipment and work stations are figured on the basis of standards established for one machine-hour of equipment operation or per unit of repair complexity (for example, cost of lubricants), per machinery set, ton of forgings, ton of parts, etc (for example, expenditures on process fuel and power for production purposes). Outlays on equipment repair are determined in conformity with maintenance personnel payroll, cost of materials for repairs on the basis of standard figures per unit of repair complexity, as well as on the basis of other figures.

To calculate depreciation allowances it is necessary to utilize standard figures established for individual types of fixed assets.

The general plant expenditures estimate includes the following items: administrative-management expenditures (wages and social insurance contributions, expenditures for business trips and transfers, bonuses to administrative-management personnel and other administrative-management costs); general operational costs (payroll of design and process engineer services personnel, maintenance and minor repairs on buildings, structures and general plant miscellaneous items, depreciation of general plant fixed assets, operation and maintenance of plant laboratories, expenditures on research, invention and efficiency innovation activities, manpower recruitment and personnel training, industrial safety, practical production experience programs, plant security, contributions to the bonus fund and other general operation expenditures); taxes, fixed charges and other mandatory contributions and expenditures.

Standard depreciation allowances, personnel lists, estimates on research activities, statistical and other data constitute the basis for preparing estimates of general plant outlays

The nonproduction outlays estimate covers cost of crating and packaging, product transport, contributions for personnel bonuses for development and adoption of new equipment, for research activities, contributions to the new equipment adoption fund, etc.

New equipment acquisition and startup fund contributions, adopted 1 January 1961, comprise the following percentages of plant production cost for various branches: heavy machine building -- 3.5; machine tools and tools -- 3.5; general machine building -- 3.0; instrument engineering -- 3.0; electrical equipment -- 3.0; radio electronic -- 2.0; automotive and bearing -- 1.0.

Including contributions to the new equipment acquisition and startup fund, nonproduction outlays of machine building and enterprises average from 3 to 7% of plant costs.

The estimate of expenditures on putting new items into production includes outlays on technical, support data and material preparations for production, as well as other outlays connected with putting new types of items into production. These expenditures are reflected as outlays of future periods and apply to the production cost of items from the moment they are put into series or mass production. As a rule outlays are recovered over a period of 2 years. This costing item does not include outlays on setting up production on a number of types of civilian machine building and metalworking products. As indicated above, they are recovered with new equipment acquisition funds.

After the above-indicated estimates have been prepared, one can proceed with costing cost of operation, workpiece, part, assembly, machine set<sup>2</sup> or machinery item as a whole.

Costing direct expenditures. Outlays on basic materials, purchased items and semimanufactures are determined with the following formula:

$$M = K_T \left( \sum_1^n m_{m\phi} C_m + \sum_1^p C_{n\phi} \right) - \sum_1^r m_{om} C_{om} \text{ rub/unit,} \quad (2.5)$$

where  $K_T$  -- coefficient which takes into account transport-initial processing costs (averaging 1.05-1.1);  $m_{m\phi}$  -- standard consumption of basic material of a given type per unit of product, taking into account minimum requisite allowances for processing and losses, in kg, t, m;  $C_m$  -- wholesale-release price of a unit of basic material in rub/kg, rub/t, rub/m (contained in Appendix 2 as an illustration are maximum wholesale-release prices for certain types of steel, and in Appendix 3 -- wholesale prices on castings, etc);  $n$  -- number of items in list of basic materials;  $C_{sm}$  -- wholesale-release price of purchased item or semimanufacture in rub/unit (Appendix 1 contains a list of basic price lists);  $p$  -- number of items in list of purchased products and semimanufactures required for making up the product;  $m_{om}$  -- standard figure on sold waste per unit of product in kg, t, m;  $C_{om}$  -- wholesale price per unit of waste by weight, in rub/kg, rub/t, rub/m (Appendix 4);  $r$  -- number of items in waste by-product list.

Figure 2.3 indicates the relationship between the specific cost of various castings, etc and their weight.

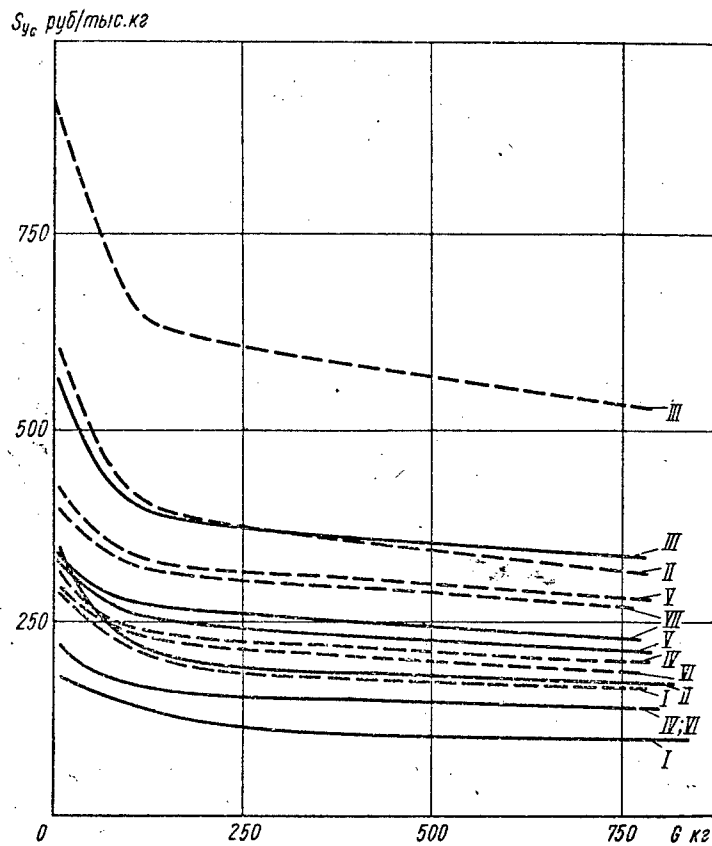


Figure 2.3. Relationship Between Specific Cost of Castings, etc and Their Weight (after L. V. Bartashev [1])

Key to figure: I -- SCh 15-32 iron castings; II -- carbon steel castings; III -- alloy steel castings; IV -- carbon steel forgings; V -- alloy steel forgings; VI -- carbon steel stampings; VII -- alloy steel stampings; solid lines -- simple items (castings with up to 2 simple cores, smooth forgings and stampings without broached holes); dashed lines, complex castings, etc

Expenditures on basic wages of production workers can be defined as the sum of estimates  $l_i$  for all manufacturing process operations:

$$L = \sum_{i=1}^m l_i = \sum_{i=1}^m \frac{C_{m_i} t_{um}}{60} = \sum_{i=1}^m \frac{C_{T_i}}{n_u} \text{ rub/unit, (2.6)}$$

where  $C_{m_i}$  -- hourly wage rate for a given job category in rub/h (Appendix 5);  $t_{un}$  -- standard time per operation in min/unit;  $n_{hr}$  -- output norm in units per hour;  $m$  -- number of operations in manufacturing process.

Costing outlays for equipment operation and maintenance. Outlays on auxiliary materials, fuel and power for process needs, on amortization of wear and tear on tools and special devices as well as other outlays on equipment maintenance and operation are determined for the individual part, set of machinery and product item in order to apply them in a substantiated manner to the cost of individual items, at estimated rates figured on the basis of machine-hour-factors. In other words the basis of these outlays is their magnitude per hour of equipment operation and number of hours required to perform a given operation.

The standard quantity of outlays per machine-hour of work  $h$  for each shop equipment group possessing close operational expenditure figures per hour of work (or for each individual unit of equipment) can be determined by dividing the sum of annual expenditures on the basis of a corresponding estimate prepared for the given equipment group, by the number of machine-hours of equipment loading per year.

The standard quantity of outlays per machine-hour of work for one of the equipment groups (usually the most widespread, leading group) or for any specific unit of equipment is taken as the base  $h_{\text{baz}}$ , and factors for the remaining equipment groups  $K_m$  are calculated in respect to it. Both standard outlay quantities and factors should be periodically revised with a change in power rate, cost of fuel, change in planned equipment work-loading, etc.

Standard quantity of outlays per machine-hour of a standard base machine tool, the machine-factor of which is 1, can be determined with the formula suggested by Professor L. V. Bartashev [1]:

$$h_{\text{baz}} = \frac{p_{\text{ob}}}{F_{\text{ef}} \sum_{i=1}^m n k_{m_i} k_{l_i}} \text{ rub/hour,} \quad (2.7)$$

where  $p_{\text{ob}}$  -- annual sum of outlays determined on the basis of estimated rates, in rubles;  $F_{\text{ef}}$  -- effective annual equipment operation time fund, in hours;  $m$  -- number of equipment groups in shop inventory;  $n$  -- number of units of equipment of a single type in group;  $k_{m_i}$  -- machine-factor of the equipment of a given group;  $k_{l_i}$  -- average work-loading factor for the equipment in a given group.

Let us assume that the shop inventory consists of 10 groups of machine tools with the following number of units in each: 20 lathes, 8 turret lathes, 3 boring machines, 5 planers, 2 slotting machines, 2 pull-broaching machines, 15 milling machines, 10 drilling machines, 6 grinding machines and 4 gear-cutting machines. Total annual shop indirect expenditures connected with equipment operation are 85,000 rubles, effective annual equipment operating time fund 4,000 hours, while work-loading factors by equipment groups and machine-factors (in parentheses) are the following: pull-broaching machines 0.4 (2.1), boring machines 0.85 (2.6), turret lathes 0.85 (1.2), grinding machines 0.85 (1.2), drilling machines 0.6 (0.6), slotting machines 0.75 (0.9),

others 0.8 (lathe machine-factors average 2.2, planers 3.7, milling machines 2.0, gear-cutting machines 1.3).

Then

$$h_{\sigma_{as}} = 85\,000:4000(20 \cdot 2,2 \cdot 0,8 + 8 \cdot 1,2 \cdot 0,85 + \\ + 3 \cdot 2,6 \cdot 0,85 + 5 \cdot 3,7 \cdot 0,8 + 2 \cdot 0,9 \cdot 0,75 + 2 \cdot 2,1 \cdot 0,4 + \\ + 15 \cdot 2,0 \cdot 0,8 + 10 \cdot 0,6 \cdot 0,6 + 6 \cdot 1,2 \cdot 0,85 + 4 \cdot 1,3 \cdot 0,8 = 20,1 \\ \text{kop/machine-hour.}$$

By multiplying the planned cost per machine-hour of base machine tool (or group) by the corresponding factors for equipment engaged in making a given part (machine set or item) and by standard time, we establish total estimated rate  $V_{cm}$ , included in the costing:

$$V_{cm} = \sum_1^m h_{\sigma_{as}} k_{m_i} t_{um_i} \text{ rub/unit,} \quad (2.8)$$

where  $H_{\text{baz}}$  -- cost per machine-hour of base machine tool (or equipment group) operation according to indirect outlays distributed with the aid of estimated rates, in rub/hr;  $k_{m_i}$  -- machine-factor taking into account difference in the cost of an hour of operation of a given tool (group) in relation to the base tool;  $t_{um_i}$  -- per-unit time norm in hours per unit;  $m$  -- number of operations in the manufacturing process.

Appendix 6 contains average machine-factor values by equipment groups [1; 5].

Determination of shop, general plant, nonproduction outlays and outlays on putting new equipment on line. Shop expenditures<sup>3</sup> and general plant outlays with a varying level of mechanization and automation of manufacturing processes on individual items should be distributed among different types of products proportional to total basic wages of production workers and direct outlays distributed by estimated rates [8].

For example, the annual shop outlays estimate is 930,000 rubles, the sum total of annual indirect expenditures distributed with the aid of estimated rates is 2,120,000 rubles, and shop basic production worker payroll is 700,000 rubles. Shop expenditures  $k_1$  will equal

$$k_1 = \frac{930\,000}{2\,120\,000 + 700\,000} \cdot 100\% = 33\%.$$

In like manner we determine the percentage of general plant expenditures  $k_2$ . For example, the sum of general plant expenditures according to the estimate equals 5,200,000 rubles, total payroll for plant basic production workers is 5,500,000 rubles, and shop indirect expenditures for all the plant's principal production shops, determined on the basis of estimated rates, is 7,500,000 rubles.

In this case the percentage share of general plant expenditures will be:

$$k_2 = \frac{5\,200\,000}{5\,500\,000 + 7\,500\,000} \cdot 100\% = 40\%.$$

Knowing  $k_1$  and  $k_2$ , shop production cost can be determined with the following formula:

$$S_{\text{sex}} = M + (L + V_{\text{c.m.}}) \left(1 + \frac{k_1}{100}\right) + L \frac{\alpha}{100} \text{ rub/unit}, \quad (2.9)$$

where  $\alpha$  -- supplementary wages of basic workers and social insurance contributions as a percentage of basic wages ( $\alpha=12-15\%$ ).

Plant production cost  $S_{\text{pl}}$  is determined with the formula

$$S_{\text{ab}} = M + (L + V_{\text{c.m.}}) \left(1 + \frac{k_1 + k_2}{100}\right) + L \frac{\alpha}{100} \text{ rub/unit}.$$

Full production cost  $S$  with formula

$$S = \left[ M + (L + V_{\text{c.m.}}) \left(1 + \frac{k_1 + k_2}{100}\right) + L \frac{\alpha}{100} \right] \times \left(1 + \frac{k_3}{100}\right) \text{ rub/unit}, \quad (2.11)$$

where  $k_3$  -- percentage of nonproduction outlays from plant production cost.

The entire sum of shop and general plant indirect outlays can be distributed proportional to basic wages of production workers by formula (1.11) only at mass and large-series production plants producing homogeneous products, with an identical degree of mechanization of production of various items, as well as at small metalworking enterprises, in tool and repair shops. This is dictated by the fact that this method gives a distorted picture of the actual cost of manufacture of each separate product.

For example, if a part was machined on a lathe with an output  $n_{\text{hr}}=20$  units (time norm 0.05 hr/unit), with a wage rate  $C_t=0.6$  rub/hr,  $M=0.1$  rub/unit,  $k_1=320\%$  of basic wages (this percentage also includes outlays connected with equipment operation),  $\alpha=15\%$ , then

$$S_{\text{sex}} = 0,1 + \frac{0,6}{20} \left(1,15 + \frac{320}{100}\right) = 0,23 \text{ rub/unit},$$

if a part is machined on a semiautomatic machine tool with  $n=200$  units, then under those same conditions

$$S_{\text{uer}} = 0,1 + \frac{0,6}{200} \left( 1,15 + \frac{320}{100} \right) = 0,113 \text{ rub/unit,}$$

that is, will be cut approximately in half.

In actuality employment of different tools, miscellaneous items and equipment will produce a change in corresponding machining expenditure items (for the most part items connected with equipment operation) not directly proportional to wage expenditures.

For example, depreciation allowance per part, with a standard depreciation for a universal lathe at 14.9% per year, and 13.4% per year for a special semiautomatic lathe, a lathe plan-specified price of 1,000 rubles, and 1,500 rubles for a semiautomatic lathe, effective equipment operation fund at 4,000 hours per year, in the first case will comprise

$$\frac{14,9 \cdot 1000 \cdot 0,05 \cdot 100}{100 \cdot 4000} = 0,19 \text{ kop/unit,}$$

and in the second

$$\frac{13,4 \cdot 1500 \cdot 100}{100 \cdot 200 \cdot 4000} = 0,025 \text{ kop/unit,}$$

that is, will diminish 7.6-fold.

If we directly calculate other indirect expenditure items, we shall become readily convinced that changes in production cost when shifting from machining a part on a lathe to a semiautomatic unit will be of a totally different character than in the above example.

The error becomes particularly substantial in distributing incorrect outlays proportional to production worker wages under conditions of highly-mechanized and automated production, in which quantity  $k_1$  may reach 500-1,000% and more. At such automated enterprises and in automated shops which produce items of a single kind, indirect outlays connected with equipment operation should be directly assigned to production cost.

Figuring in outlays on putting new items into production. If expenditures for putting new items into production are financed not from the new product fund, we must add to the above formula (2.11) expenditures on putting into production new items (by estimate) in rubles  $P_{oc}$ , applied to the plan-specified 2-year production schedule after completion of the period of production startup, in units  $N_2$  year. Then

$$S = \left[ M + (L + V_{cm}) \left( 1 + \frac{k_1 + k_2}{100} \right) + L \frac{a}{100} \right] \times \\ \times \left( 1 + \frac{k_3}{100} \right) + \frac{P_{oc}}{N_{2 \text{ год}}} \text{ rub/unit,} \quad (2.12)$$

Wholesale-release price. Product wholesale-release price  $C$ , established for an enterprise, is calculated proceeding from plan-specified branch average production cost (in those instances where a product is to be turned out at several plants) and a specified percentage of profit:

$$C = \phi S_{cp}, \quad (2.13)$$

where  $\phi$  -- a factor which takes into account plan-specified profit (for a new machine-building product, when establishing temporary wholesale-release prices the average coefficient value is adopted in the amount of 1.10);  $S_{cp}$  -- average branch production cost in rub/unit.

As an illustration, we include below production and wholesale-release price costing by expenditure items, in rubles.

Basic materials, minus recoverable waste	540.0
Purchased items and semimanufactures	1,060.0
Basic wages	128.0
Supplementary wages and social insurance contributions	19.0
Equipment operation and maintenance	410.0
Shop expenditures (33% of basic wages and expenditures on equipment operation and maintenance)	177.5
General plant expenditures (40% of total basic wages and expenditures on equipment operation and maintenance)	215.5
Plant production cost	2,550.0
Nonproduction outlays, including contributions to the new product startup fund (3% of plant production cost)	76.5
Full production cost	2,626.0
Enterprise wholesale-release price (profit 10%)	2,889.0

### 3. Direct Count of Expenditures Connected with Equipment Operation

With the direct count method, in addition to expenditures on basic materials, semimanufactures, component items and expenditures on basic production worker wages, one determines expenditures on operation and maintenance (resharpening and wear) of tools and dies, expenditures on accessories utilization (depreciation and repairs), expenditures on process energy, expenditures on equipment minor repairs, and equipment depreciation allowance.

By the direct count method shop production cost is calculated with the following formula:

$$S_{uex} = M + (L + I + P + E + R + A) \left( 1 + \frac{k_4}{100} \right) + L \frac{a}{100} \text{ rub/unit}, \quad (2.14)$$

where  $I$  -- expenditures on operation and maintenance of tools and dies, in rub/unit;  $P$  -- expenditures on operation and maintenance of accessories, in

rub/unit; E -- expenditures on process energy, in rub/unit; R -- expenditures on minor repairs, in rub/unit; A -- equipment depreciation allowances, in rub/unit;  $k_4$  -- percentage share of remaining shop indirect expenditures ( $k_4 \geq k_1$ ).

Shop expenditures  $k_4$  are distributed proportional to the sum of basic wages and expenditures connected with equipment operation ( $I+P+E+R+A$ ).

The greater the number of shop expenditure items are determined by the direct count method, naturally there is secured a greater accuracy of calculations of the production cost of a given specific item. Distribution of expenditures proportional to one or several items will always cause distortion of calculations, as noted above. Therefore there is quite understandably an endeavor to include an even greater number of items in direct expenditures [5] and, in particular, outlays on auxiliary materials (abrasives, lubricants, etc), that portion of expenditures applying to a given work station, on depreciation on production space, on shop lighting, etc.

However, nevertheless one should bear in mind that as a rule the expenditures contained in formula (2.14) are of dominant significance among outlays which can be determined by the direct count method (this applies particularly to automated conditions of production).

Let us examine the direct count methods for several expenditure items included in product costing.

A consolidated calculation of expenditures on use and maintenance of cutting tools can be performed on the basis of the average statistical figures in Appendix 7, which specifies the average cost per hour of cutting tool operation at plants of the automotive-tractor industry, calculated on the basis of the Scientific Research Institute of Automotive, Tractor, and Agricultural Machine Building Technology according to the following formula:

$$I_p = \frac{I_u t_{\text{mach}}}{60} \text{ rub/unit,} \quad (2.15)$$

where  $I_p$  -- per-operation expenditures on cutting tools, in rubles per unit;  $I_{\text{hr}}$  -- cost of 1 hour of cutting tool operation, in rubles per hour;  $t_{\text{mach}}$  -- tool working time in the course of an operation, in minutes.

Expenditures on cutting tools on a per-operation basis are determined more precisely with the formula

$$I_p = \frac{C_n + n_n S_n}{\tau_{\text{cm}} (n_n + 1)} t_{\text{mach}} \text{ rub/unit,} \quad (2.16)$$

where  $C_n$  -- original tool cost (plan-specified price) in rubles per unit;  $n_n$  -- number of resharpenings to a fully worn-out state;  $S_n$  -- cost of one resharpening, in rubles per unit;  $\tau_{\text{cm}}$  -- period of durability between two

resharpenings, in hours;  $t_{mach}$  -- duration of tool work in the course of an operation, in hours (according to the figures of the All-Union Scientific Research Institute of Standardization in Machinery Manufacture [3];  $t_{mach}$  under conditions of series production averages 50%, in large-series production 60%, and in mass production 70% of  $t_{un}$ ).

In like manner per-operation expenditures on utilization of dies  $I_d$  can be determined on the basis of one of the following formulas:

$$I_u = \frac{S_u + S_{p,u}}{\tau_{cm,u}(n_n + 1)} t_{mau} \text{ rub/unit} \quad (2.17)$$

or

$$I_u = \frac{S_u + S_{p,u}}{T_u N_{zod}} \text{ rub/unit}, \quad (2.18)$$

where  $S_{p,d}$  -- cost of die repair and regrinding to a completely worn-out state over the course of a period over the course of which the cost of making and repairing the die is written off;  $N_{year}$  -- year's production schedule in units.

Total outlays on tools  $I$  per unit of product are determined with formula

$$I = \sum_1^m I_p + \sum_1^m I_u, \quad (2.19)$$

where  $m$  -- number of operations in the manufacturing process.

Expenditures on operation and maintenance of special devices per unit of product  $P'$  are determined with the formula

$$P' = 0,6 \frac{S_n}{N_{zod}} \text{ rub/unit}, \quad (2.20)$$

where  $S_n$  -- cost of device in rubles per unit.

The factor 0.6 in the formula takes into account both the magnitude of annual depreciation allowance, which with a 2-year writeoff period can be pegged at 50%, and annual outlays on repair of devices, comprising 8-10% of their cost.

The nomogram contained in Figure 2.4 can be used for consolidated calculations of the cost of producing these devices [1].

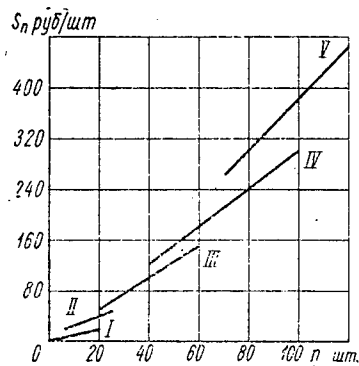


Figure 2.4. Relationship Between Cost of Manufacturing Devices and the Number of Parts and Complexity Group (designated by numbers)

Key to figure: I -- simple lathe centers, holders, jigs, vee-blocks; II -- vee-blocks with clamping parts, welded and riveted jigs for simple parts, simple chucks, mandrels, devices for milling strips and wedges; III -- jigs for complex parts, simple-construction swivel tables, devices for 2-3 axes, simple indexing attachments; IV -- boring machine attachments for body parts, multiple-spindle heads, complex devices and jigs; V -- special multiple-axis boring fixtures, special fixtures for milling in several planes, complex indexing attachments and swivel tables

Expenditures on operation and maintenance of universal devices, per operation  $P''$ , can be determined in a manner similar to expenditures on die operation and maintenance [formula (2.17)].

Overall expenditures on devices  $P$  per unit of product are determined with formula

$$P = \sum_{i=1}^m P' + \sum_{i=1}^m P''. \quad (2.21)$$

Expenditures on process electricity  $E_1$  are calculated with the following formula:

$$E_1 = C_{el} \sum_{i=1}^m k_{ec} N_y t_{max}, \quad (2.22)$$

where  $C_{el}$  -- cost per kilowatt hour of electricity, in rubles (averaging 0.01-0.015);  $k_{ec}$  -- electric motor load factor (demand factor -- see Appendix 8);  $N_y$  -- electric motor or current collector installed power/capacity, in kilowatts.

Expenditures on process electricity can be calculated approximately with the following formula:

$$E_1 = \sum_{i=1}^m \frac{E_u t_{max}}{60} \text{ rub/unit}, \quad (2.23)$$

where  $E_{hr}$  -- hourly expenditures on process electricity in rubles (see Appendix 9) [5].

We can calculate expenditures on other types of energy (gas, compressed air, etc) in like manner. The sum of all expenditures (including cost of process electricity) comprises item E in formula (2.14).

Expenditures on maintenance repairs (other than major overhauls) and servicing between repairs per unit of product can be determined most precisely on the basis of the standard figures of the Uniform Scheduled-Preventive Maintenance System:

$$R = \sum_{i=1}^m \frac{HR_{ca}}{F_{\text{эф}}} t_{um}, \quad (2.24)$$

where H -- average magnitude of expenditures per unit of repair complexity, per year, in rubles;  $R_{co}$  -- machine tool repair complexity category;  $F_{ef}$  -- annual effective equipment operating time fund, taking into account utilization time factor, in hours;  $t_{un}$  -- per-unit time norm, in hours; m -- number of operations in manufacturing process.

The approximate value of expenditures on maintenance repairs per hour of operation  $R_{hr}$  can be determined with the formula suggested by the All-Union Scientific Research Institute of Standardization in Machinery Manufacture [3]:

$$R_u = 0,5 \left( \frac{R_m}{141} + \frac{R_e}{388} \right) \text{ rub/unit}, \quad (2.25)$$

where  $R_m$  -- equipment mechanical repair complexity category;  $R_e$  -- equipment electrical repair complexity category; 0.5 -- factor taking into account equipment down time (15-25%), conversion of kopecks to rubles and minutes to hours.

L. I. Gamrat-Kurek et al [5] have proposed a method of calculating expenditures per hour of operation on this item, which makes it possible also to take into account expenditures on auxiliary materials expended on equipment maintenance (coolants, etc):

$$R_u = a_1 R_m + a_2 R_e, \text{ rub/hour}, \quad (2.26)$$

where  $R_{hr}$  -- expenditures on repairs, servicing between repairs and auxiliary materials, in rubles per hour;  $a_1, a_2$  -- constants.

Appendix 10 contains formulas for calculating outlays per hour of operation  $R_{hr}$ .

Taking into account  $R_{hr}$ , expenditures  $R$  will be:

$$R = \sum_{i=1}^m \frac{R_i t_{um}}{60} = \sum_{i=1}^m \frac{R_i}{n_u} \text{ rub/unit, (2.27)}$$

where  $t_{un}$  -- time norm in minutes per unit;  $n_{hr}$  -- hourly output norm in units per hour.

L. V. Bartashev and L. I. Gamrat-Kurek [2], on the basis of an analysis of the Uniform Scheduled-Preventive Maintenance System, suggest for the purpose of comparative consolidated calculations (for example, in analyzing process variants) determining  $R$  in relation to magnitude of depreciation allowance  $A$ :

for metal-cutting machine tools, forge pressing and molding sand preparation equipment

$$R=0.33A \text{ rub/unit; (2.28)}$$

for principal foundry equipment and welding equipment

$$R=0.2A \text{ rub/unit; (2.29)}$$

for materials handling and transfer equipment

$$R=(0.15-0.3)A \text{ rub/unit. (2.30)}$$

Factor 0.15 is applied for machinery where expenditures on major overhauls and medium repairs comprise 25% of total depreciation allowance; a factor of 0.3 is applied to machinery for which these expenditures reach 60%.

The following formula is employed to calculate depreciation allowance to full recovery and major overhaul of special equipment per unit of output  $A'$ :

$$A' = \frac{a' (C_{obn} - C_{ocm}) + a'' C_p}{100 N_{zod}} \text{ rub/unit, (2.31)}$$

and universal equipment  $A''$ :

$$A'' = \frac{[a' (C_{obn} - C_{ocm}) + a'' C_p] t_{um}}{100 F_{\partial\phi}} \text{ rub/unit, (2.32)}$$

where  $a'$  -- annual standard depreciation allowance to full recovery of fixed assets;  $a''$  -- annual standard depreciation allowance for major overhaul;  $C_{obn}$  -- plan-specified (balance-sheet) equipment price, including expenditures on transport-initial processing operations and installation, in rubles per unit;  $C_p$  -- outlays on major overhaul during the period of depreciation, in rubles;  $C_{osm}$  -- equipment residual values, rubles;  $N_{year}$  -- equipment

annual productivity, in units;  $t_{un}$  -- per-unit time norm, in hours;  $F_{ef}$  -- annual effective equipment operation time fund, taking into account utilization factor, in hours.

Annual equipment operation fund with two-shift operations, can be assumed to be between 3,900 and 4,000 hours; the utilization factor is adopted on the basis of shop or enterprise figures, and in the absence of such figures a factor of 0.7 is adopted for series production, and 0.75 for large-series production.

Plan-specified equipment price is determined with the formula

$$C_{обн} = k_n C_{об},$$

where  $k_n$  -- a factor which takes into account outlays on transport-initial processing and installation operations (average value  $k_n=1.1$ );  $C_{об}$  -- equipment wholesale-release price, in rubles.

Table 2.5 contains an equipment annual operation time fund by shifts.

Table 2.5. Annual Equipment Operation Fund, in hours

1 Оборудование	2 При работе		
	3 в одну смену	4 в две смены	5 в три смены
6 Металлорежущие станки с категорией сложности $R_{сл}$ до 30 . . . . .	2000	3950	5870
7 Металлорежущие станки с $R_{сл}$ свыше 30 . . . . .	—	3830	5500
8 Кузнечно-прессовое оборудование . . . . .	—	3830	5500
9 Литейное оборудование . .	1980	3870	5685

Key to table: 1 -- equipment; 2 -- operation; 3 -- single-shift; 4 -- two shifts; 5 -- three shifts; 6 -- metal-cutting machine tools with a complexity category  $R_{co}$  to 30; 7 -- metal-cutting machine tools with  $R_{co}$  above 30; 8 -- press forging equipment; 9 -- foundry equipment

Total depreciation allowance is equal to

$$A = \sum_1^m A' + \sum_1^m A'' \text{ rub/unit,} \quad (2.33)$$

where  $m$  -- number of operations in manufacturing process.

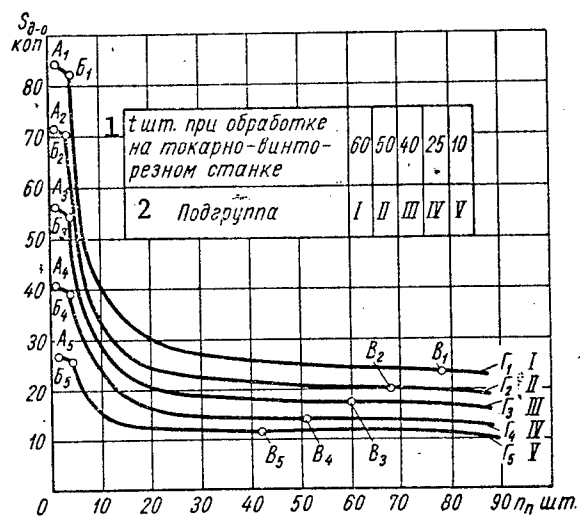


Figure 2.5. Relationship Between Part-Operation Cost and Size of Production Batch (Machining Stepped Shafts Weighing from 130 kg)

Key to figure: AB -- machining on engine lathe; BB -- machining on multiple-cutter single-spindle semiautomatic lathe; BF -- machining on multiple-cutter six-spindle semiautomatic lathe; 1 -- machining on an engine lathe; 2 -- subgroup

On the basis of element-by-element calculation of principal expenditure items for parts of a given class, one can elaborate convenient graphs which will make it possible quickly to determine the designed cost per part-operation. Figure 2.5 contains a graph elaborated by B. G. Shmelev, for calculating the part-operation cost on stepped shafts weighing from 1 to 30 kg. With the graph it is easy to determine the part-operation cost in relation to selected equipment.

#### 4. Employment of the Direct Expenditure Count Method for Costing Manufacturing Process Variants

Modern manufacturing processes make it possible fairly frequently to obtain parts, assemblies and units in full conformity with the specified manufacturing conditions by means of several techniques. Therefore it is necessary initially to determine the basically possible manufacturing process variants for producing finished parts, assembly of units and assemblies, to select the economically expedient variant, and only then to carry out its detailed process elaboration.

In those cases where differing workpieces, equipment, accessories, etc are employed in different variants, and correspondingly workers of differing level of skills, in order to select the most economical variant it is necessary to calculate the cost of manufacture in each. The lowest cost of

producing a part, assembly or unit, while ensuring specified technical conditions, will determine the most economical manufacturing process variant.

With such comparative calculations there is no need to perform an element-by-element calculation of all expenditure items entering into cost of production. Wages of engineers, technicians and shop office personnel, depreciation on warehouse facilities, administrative and management personnel wages plus many other shop, general plant and nonproduction expenditure items are independent of the selected type of equipment or other manufacturing process elements. At the same time, with such comparative calculations it is impossible to apply conventional costing methods, whereby some shop outlays apply to production cost proportional to the wages of basic production workers or proportional to the sum of wages and estimated rates. Such methods can lead to substantial error in comparative calculations and will not make it possible to select the most economical variant.

Necessary in this connection is an element-by-element calculation of only those outlays which change appreciably with a change in the manufacturing process variant. Eliminated from the calculation are identical or insignificantly-changing elements of production cost in the compared variants, as well as elements which are independent both of variant and other factors (for example, administrative, housekeeping and other costs).

The sum of expenditures which change in relation to manufacturing process variant is normally called process cost [tekhnologicheskaya sebestoimost'].

Expenditures on one item, together comprising process cost, are broken down into two main groups (see page 95): into expenditures proportional to output volume, or variable,  $v_r$ , and expenditures not proportional to output volume, or fixed-constant,  $c_n$ .

Table 2.6 divides those expenditure items most frequently encountered in process cost into variable and fixed constant. In conformity with the expenditures grouping employed in Table 2.6, the process cost of a part, assembly or unit  $S_m$  is equal to

$$S_m = \sum_1^m v_r + \frac{\sum_1^m c_n}{N_{np}} \text{ rub/unit,} \quad (2.34)$$

where  $m$  -- number of operations in manufacturing process;  $N_{np}$  -- production schedule, units.

Minimum  $S_m$  in the analyzed variants characterizes that variant which is most economical for the given production schedule.<sup>5</sup>

Calculation of all principal process cost items was examined in sections 2 and 3 of this chapter. Other items of process cost required for any concrete analysis can be calculated in like manner.

Table 2.6. Grouping of Product Process Cost Expenditures

Статьи затрат	1	$v_r$	$c_n$
<b>2 Прямые затраты</b>			
3 Основные материалы и полуфабрикаты . . . . .		+	
4 Заработная плата основных производственных рабочих:			
5 сдельная . . . . .		+	
6 повременная . . . . .			+
<b>7 Затраты, связанные с работой оборудования</b>			
8 Заработная плата рабочих, занятых обслуживанием оборудования . . . . .			+
9 Материалы для содержания производственного оборудования . . . . .			+
10 Топливо для технологических целей . . . . .		+	
11 Электроэнергия, пар, вода, газ для технологических целей . . . . .		+	
Амортизационные отчисления: 12			
по универсальному оборудованию 13 . . . . .		+	
специальному оборудованию 14 . . . . .			+
Эксплуатация приспособлений: 15			
16 универсальных . . . . .		+	
17 специальных . . . . .			+
Эксплуатационные ремонты оборудования и межремонтное обслуживание 18 . . . . .		+	
Эксплуатация инструментов 19 . . . . .		+	
<b>Общехозяйственные затраты 20</b>			
Эксплуатация транспорта 21 . . . . .		+	
Амортизация зданий и сооружений цеха 22 . . . . .			+

Key to table: 1 -- expenditure items; 2 -- direct outlays; 3 -- basic materials and semimanufactures; 4 -- wages of basic production workers; 5 -- piece-rate; 6 -- hourly; 7 -- expenditures connected with equipment operation; 8 -- wages of workers employed in equipment servicing and maintenance; 9 -- materials for maintenance and operation of production equipment; 10 -- fuel for process purposes; 11 -- electricity, steam, water, gas for process purposes; 12 -- depreciation allowance; 13 -- on universal equipment; 14 -- special equipment; 15 -- operation and maintenance of devices; 16 -- universal; 17 -- special; 18 -- equipment maintenance repairs and servicing between repairs; 19 -- tool maintenance; 20 -- general plant expenditures; 21 -- transport operation and maintenance; 22 -- depreciation on buildings and shop structures

In particular, for example, the quantity of depreciation allowance based on cost of production facilities  $A_{пл}$  can be determined with the formula

$$A_{пл} = \frac{a_{пл} c_{пл} w_{пл}}{100 F_{эф}} t_{ум} \text{ rub/unit,} \quad (2.35)$$

where  $a_{ar}$  -- percentage of annual depreciation allowance based on cost of production facilities;  $c_{ar}$  -- cost of production space in rub/m<sup>2</sup>;  $w_{ar}$  -- size of area occupied by equipment (including aisles and corridors), m<sup>2</sup>;  $F_{ef}$  -- annual effective equipment operating time fund, taking utilization factor into account, hours;  $t_{un}$  -- per-unit time norm, hours.

The methods of calculating production cost examined in this chapter make it possible to establish the plan-specified cost of producing a designed machinery item. The most accurate method is the method of direct calculation of all principal expenditures, particularly expenditures on basic materials, production worker wages, and expenditures connected with equipment operation. Utilization of this method makes it possible to perform an economic analysis of different variants of manufacturing processes which can be employed for the manufacture of a designed machinery item.

#### FOOTNOTES

1. In order to simplify costing, expenditures on fuel and power for process needs, on amortization of wear on tools and special devices are included in outlays on equipment operation and maintenance.
2. Machine set is defined as the aggregate of workpieces or parts manufactured or machined in a given shop and designated for making up one unit of machinery.
3. All expenditures other than those on equipment operation and maintenance distributed by estimated rates.
4. The comparatively small percentage of shop expenditures obtained in this example is due to the fact that a substantial portion of indirect shop expenditures has already been figured in production cost with the aid of estimated rates. Therefore in some cases the percentage share of shop expenditures not distributed with the aid of estimated rates may prove smaller than the share of general plant expenditures, which is practically impossible with distribution of all indirect expenditures proportional to basic wages of production workers.
5. For more detail on selection of the most effective manufacturing process, see [1], as well as Tilles, S. A.: "Ekonomika tekhnologicheskikh protsessov mekhanicheskoy obrabotki" [Economics of Machining Processes], Moscow, Mashgiz, 1964; Charnko, D. V.: "Osnovy vybora Tekhnologicheskogo protsessa mekhanicheskoy obrabotki" [Fundamentals of Selection of Machining Process], Moscow, Mashgiz, 1963.

### CHAPTER 3.

#### ECONOMICALLY ALLOWABLE (MAXIMUM) PRODUCTION COST AND MACHINERY PRICE

##### 1. Quality of Machinery and Wholesale Prices

In many cases the cost of producing a machinery item, obtained by calculation at the preproduction design or engineering stage, may prove higher than the cost of producing the machine it is to replace. Such cases are also characteristic for comparative analysis of different variants of a new design. The greater production cost of one variant or greater production cost (and correspondingly greater wholesale price as well) of a newly-designed machinery item in comparison with the old model by no means signifies that the given variant should not be put into production. Substantial qualitative advantages may be achieved in the new design: higher productivity, greater durability, reliability, lower operating and maintenance cost, etc, which in the final analysis will provide substantial savings in the area of operation and not only will fully cover but will more than cover the increased cost of production and greater wholesale-release price of the new-design machinery.

Table 3.1 contains as an illustration indices on items produced by plants A and B (the items differ in service life).

It is apparent from Table 3.1 that the product turned out by plant B is more advantageous to the economy but requires greater production outlays. If we establish an equal level of wholesale-release prices for the products of these plants, plant B will prove to be under significantly worse conditions, since its profit and level of profitability, with an approximately identical composition of productive assets, will be substantially lower. The possible result is that plant B will consider it disadvantageous to turn out a more durable product, although this would bring substantial savings to the economy.

In connection with this there arises the problem of determining the allowable (maximum) level of production cost and wholesale-release price on a new, better-quality product, whereby a plant would be provided incentive to put

Table 3.1. Economic Indices of Manufacture of Similar Items by Two Plants

№ по пор.	15 Показатели	16 Изделие завода	
		А	Б
1	План в тыс. шт. . . . .	2 000	2 000
14	Выполнение плана:		
2	в тыс. шт. . . . .	2 100	2 000
3	в % . . . . .	105	100
4	Производительность труда в % . . . .	103	100
5	Накопления в млн. руб. . . . .	5,0	2,5
6	Долговечность в единицах работы . .	35 000	40 000
7	Суммарная долговечность всей продук-		
	ции в млрд. единиц работы . . . . .	73,5	80
8	Избыточная долговечность в млрд. еди-		
	ниц работы . . . . .	—	6,5
9	Натуральный эквивалент избыточной		
	долговечности в тыс. шт. (п.8:п.6) . .	—	162
10	Сумма реализации продукции в млн.		
	руб. . . . .	105	100
11	Затраты на продукцию на единицу ра-		
	боты в руб. (п.10:п.7) . . . . .	0,00141	0,00125
12	Экономия на единицу работы в руб. . .	—	0,00015
13	Экономия по всей продукции завода Б		
	в млн. руб. (п.12×п.7) . . . . .	—	12,8

Key to table: 1 — plan target, thousand units; 2 — thousand units; 3 — as a percentage; 4 — labor productivity, percentage; 5 — accumulation, million rubles; 6 — service life in operation units; 7 — total service life of entire output, in billion operation units; 8 — surplus service life, in billion operation units; 9 — physical equivalent of surplus service life, in thousand units; 10 — sum realized on sale of output, million rubles; 11 — outlays on production per unit of work, in rubles; 12 — savings per unit of operation, in rubles; 13 — savings on all output of plant B, million rubles; 14 — plan target fulfillment; 15 — indices; 16 — item produced by plant

this item into production, where there would be adequate savings to the economy and incentive for customers to purchase it. In the final analysis prices should be established taking into account the entire complex of technical-economic parameters of the given machine, with incentive both for design organizations and plants to produce advanced equipment for the nation's economy.

## 2. Calculation of Allowable (Maximum) Production Cost and Price

As we know, the principal criterion in technical-economic analysis of new equipment is the criterion of calculated specific outlays.<sup>1</sup>

In the general case this criterion can be expressed as

$$S_{\text{эк}} + E_{\text{н}} C_{\text{у}}, \quad (3.1)$$

where  $S_{ek}$  -- specific operating expenditures in rubles per unit of productivity (see Figure 1);  $C_y$  -- specific capital investment in rubles per year per unit of productivity;  $E_s$  -- branch standard coefficient of comparative economic effectiveness -- a quantity inverse to period of recovery of investment.

We give below standard periods of recovery of investment  $\tau_s$  and effectiveness factors  $E_s$  for several sectors and branches.

Branch/Sector	$\tau_s$ (years)	$E_s$ (1/year)
Metallurgy (ferrous and nonferrous)	7	0.14
Power Engineering	7-10	0.14-0.10
Machine building	3-5	0.33-0.2
Light industry	3-5	0.33-0.2
Construction industry	6	0.17
Transportation	10	0.10

In determining the effectiveness of new equipment models utilized in various branches and sectors, that is, possessing intersectorial or interbranch significance, we can adopt the average standard quantity  $E_s=0.15$ .

Maximum periods of recovery of investment and minimum effectiveness factors with mechanization and automation of production are given below.

The best equipment variant is determined by the smallest sum of calculated specific outlays:

$$S_{sk} + E_k C_y \rightarrow \min. \quad (3.2)$$

In conformity with the "Standard Method of Determining Economic Effectiveness of Capital Investment," the economic effectiveness of developing new or improving existing types of machinery, equipment, mechanisms and other implements of labor is achieved at points of operation and is determined by comparison of the purchaser's capital investment with decrease in the cost of products or operations performed with the aid of these implements of production. An increase in the cost of machinery manufacture is viewed as additional capital investment by the equipment purchaser, compared with a decrease in current (operating) expenditures.

Therefore we can determine allowable (maximum) wholesale-release price and allowable (maximum) cost of producing a newly-designed machinery item on the basis of the following considerations. Let us assume that the machinery item currently in production has calculated specific outlays equal to

$$S_{sk_c} + E_k C_{y_c} \text{ rub/unit of productivity,}$$

while the new model, with the same number of units produced, is as follows:

$$S_{sk_n} + E_k C_{y_n} \text{ rub/unit of productivity.}$$

Measures	$\tau_{\max}$ (years)	$E_{\min}$ (1/year)
Small-scale mechanization and automation of production (adoption of simple types of equipment, installation of instruments and devices on operating equipment, equipment modernization, etc)	1.5	0.67
Mechanization and automation of individual processes and operations, modernization of equipment with a long service life and maintenance cycle, and partial replacement of equipment, new manufacturing processes with partial replacement of equipment	3	0.33
Adoption of totally mechanized and automated production processes, installation of automated production lines and shops without revision of process arrangement, adoption of totally new manufacturing processes	5	0.2
Total mechanization and automation of production processes in sections, shops and at enterprises, with total retooling and revision of the production process layout, measures aimed at specialization, cooperative manufacture, integration, development of new types of materials	6	0.17

The maximum wholesale-release price  $C'_{nnp}$  of the newly-designed equipment, that is, the purchaser's capital investment, not including cost of shipping and installation, is obtained from an equality of both equations:

$$S_{\partial K_c} + E_n C_{y_c} = S_{\partial K_n} + E_n C_{y_n},$$

whence

$$C_{y_n} = \frac{S_{\partial K_c} - S_{\partial K_n}}{E_n} + C_{y_c} \frac{\text{rubles per}}{\text{unit of production}}, \quad (3.3)$$

$$C'_{nnp} = \left( \frac{S_{\partial K_c} - S_{\partial K_n}}{E_n} + C_{y_c} \right) W_n \text{ rub/unit}, \quad (3.4)$$

where  $W_n$  -- annual productivity of the newly-designed equipment in units of productivity per year, while maximum production cost  $S'_{nnp}$ , proceeding from standard profit within a range of 10%,

$$S'_{nnp} = 0,91 \left( \frac{S_{\partial K_c} - S_{\partial K_n}}{E_n} + C_{y_c} \right) W_n \text{ rub/unit. (3.5)}$$

Let us assume that with an identical scale of manufacture  $C_0=500$  rubles per unit;  $S_{ek_0}=1$  rub/unit of productivity;  $W_0=500$  units of productivity per year;  $S_{ek_n}=0.8$  rubles per unit of productivity;  $W_n=550$  units of productivity per year;  $E_n=0.2$  1/year.

Then maximum price and item production cost will equal

$$\begin{aligned} C_{y_c} &= \frac{C_c}{W_c} = \frac{500}{500} = 1 \text{ rub/unit of productivity;} \\ C'_{nnp} &= \left( \frac{1-0,8}{0,2} + 1 \right) 550 = 1100 \text{ rub/unit;} \\ S'_{nnp} &= 0,91 \cdot 1100 = 1000 \text{ rub/unit,} \end{aligned}$$

that is, the price obtained by calculation cannot exceed the wholesale price of the replaced equipment by more than 2.2-fold.

With formulas (3.4) and (3.5) we can analyze not only the influence of increase in productivity on maximum price and production cost but also the influence of a number of other factors as well. In particular, an increase in service life and improved reliability of newly-designed equipment are reflected in the indicated formulas in the magnitude of specific operating and maintenance costs of the new machinery  $S_{ek_n}$ .

As a rule these costs, per unit of machinery produced or work performed, decrease, since there is a decrease in the number of machinery malfunctions, breakdowns, and failures; time between repairs increases; annual repair costs decrease; the term of depreciation increases; the annual depreciation allowance decreases; annual machinery useful utilization time increases; machinery annual productivity increases, which leads to a decrease in outlays per unit of output or productivity.

The relative or absolute decrease in operating expenses on fuel, power, servicing, etc, engineered into the new piece of equipment by the designer, also reduces the machine's unit operating cost  $S_{ek_n}$ .

### 3. Analysis of Calculated Quantities and Determination of Economically Allowable (Maximum) Production Cost and Price

The obtained machinery production cost and wholesale price must be compared with calculated maximum production cost and price  $S_{nnp}$  and  $C_{nnp}$ ; when  $S_n > S'_{nnp}$  a design is economically ineffective and should not be adopted if

this new equipment does not pursue any special objectives (for example, easing labor, improving industrial safety, etc). If  $S_n = S'_{nnp}$  and, what is more important for the purchaser,  $C_n = C'_{nnp}$ , he will obtain real savings from purchasing the new equipment in place of old equipment only beyond the limits of the standard term of recovery of investment (in the above example  $\tau = 5$  years, that is, the purchaser's additional capital investment will be recovered not sooner than standard term  $\tau_s$ ). This of course is not sufficiently effective for achieving savings to the economy.

In many cases a machine's designed productivity is not achieved immediately, while in certain cases it is never achieved, due to a lower shift factor and greater down time for repairs in comparison with the figures employed in the calculations, worse utilization of output capacity, etc. Therefore the obtained values  $S'_{nnp}$  and  $C'_{nnp}$  should be viewed only as maximum, not as values toward which designers should strive. In other words a wholesale-release price established at the level  $C'_{nnp}$  will be advantageous only to the manufacturer, since added to the price of the old machine is all the savings obtained from operation during the standard term of recovery of investment. The purchaser of this product may even show worse operational economic indices.

Thus conditions  $S_n < S'_{nnp}$  and  $C_n < C'_{nnp}$  should always be observed in designing new machinery.

On the other hand one should bear in mind that calculated machinery production cost  $S_n$  is not immediately achieved by the manufacturer. At the pre-production design stage it is established on the basis of application of the method of analogy (see Chapter 1), utilizing as initial input data the technical-economic indices (materials requirements, labor requirements, production cost) of similar machinery currently in production. In establishing planned production cost (see Chapter 2), the calculation once again is based on the conditions of production up to the plan-specified output figures (as a rule, in the second year of manufacture).

The actual initial machinery production cost, particularly in the first year of series (mass) production, may substantially exceed the amount obtained by calculation. In this case the manufacturer, under conditions where wholesale-release price  $C_n$  is established on the basis of calculated or average branch production cost, may get into difficulty due to a decrease in the profitability of producing the new item, and possibly a production loss situation.

In connection with this, a large understatement of  $S_n$  and correspondingly  $C_n$  in comparison with  $S'_{nnp}$  and  $C'_{nnp}$  can lead to difficulties in putting new items into production at the manufacturing plant, particularly with a limited product mix or a large percentage share of a given type of machinery in the total output.

In what way should the savings obtained by employment of a new piece of machinery be distributed between customers and manufacturer? In setting a machinery price, alongside ensuring savings to the purchaser, it is essential to secure a profitability level which will not lead to a worsening of the operation economic indices of the manufacturer. In any case profitability on the new machinery should be no less than on previously-manufactured equipment, and when production startup has been completed on a totally new piece of machinery for the given plant, it should be not lower than the average level of profitability obtained on the manufacture of other principal product items.

Thus the following minimum condition should be met:

$$\frac{C_n - S_n}{S_n} = \frac{C_c - S_c}{S_c} = p \quad (3.6)$$

or, designating  $C - S = P_p$  (profit),

$$\frac{P_{p_n}}{S_n} = \frac{P_{p_c}}{S_c} = p, \quad (3.7)$$

where  $p$  -- profitability of machine production.

In addition, condition [13] should be observed

$$\frac{H_n + H_e}{\Delta K + \Delta C} \geq E_n, \quad (3.8)$$

where  $H_n$  -- annual production savings calculated per machine unit, in rubles;  $H_e$  -- annual operations savings, per machine unit, in rubles;  $\Delta K$  -- additional capital investment in the production sphere, per machine, in rubles [if funds for new equipment are allocated from the new product startup fund (see page 94), then  $\Delta K$  can be ignored, since in this case they are reflected in production cost through the appropriate nonproduction expenditures item];  $\Delta C$  -- additional capital investment in the area of operation, per machine, in rubles;  $E_s$  -- standard economic effectiveness factor in 1/year (in those cases where the customer enterprises and manufacturer are in branches possessing differing quantity  $E_s$ , the average factor value for the industry is adopted, 0.15).

Proceeding from the above formulas (3.6) and (3.8), we obtain quantities  $S_{nnp}$  and  $C_{nnp}$ . We shall figure that  $\Delta C = C_n - C_o$ . From equation (3.6) we obtain

$$\frac{C_n}{S_n} - 1 = \frac{C_c}{S_c} - 1 = p,$$

or

$$\frac{C_n}{S_n} = \frac{C_c}{S_c} = p + 1.$$

Annual savings in machinery production will be expressed as

$$H'_n = S'_o - S'_n \text{ rub/year}, \quad (3.9)$$

where  $S'_o$  and  $S'_n$  -- production cost of the annual machinery production schedule, old and new equipment, in rubles per year.

Calculated per machine

$$S_c = \frac{S'_c}{N_{200}} \quad \text{and} \quad S_n = \frac{S'_n}{N_{200}};$$

whence

$$H_n = S_o - S_n \text{ rub/unit}, \quad (3.10)$$

while annual savings in operating costs per machine will equal

$$H_g = (S_{gk_o} - S_{gk_n}) W_n = \Delta S_{gk} W_n \text{ rub/unit}, \quad (3.11)$$

where  $S_{ek_o}$  and  $S_{ek_n}$  -- specific operating costs for the old and new machine in rubles per unit of productivity;  $W_n$  -- annual productivity of the new machine, in units of productivity per year.

We shall transform inequality (3.8)

$$H_n + H_g \geq E_n \Delta K + E_n \Delta C$$

and substitute corresponding component values:

$$\begin{aligned} S_c - S_n + \Delta S_{gk} W_n &\geq E_n \Delta K + E_n C_n - E_n C_c; \\ S_c + \Delta S_{gk} W_n - E_n \Delta K + \\ + E_n S_c (1 + p) &\geq S_n + E_n S_n (1 + p); \\ S_c (1 + E_n + E_n p) + \Delta S_{gk} W_n - E_n \Delta K &\geq \\ &\geq S_n (1 + E_n + E_n p). \end{aligned}$$

In this case the production cost of the newly-designed machinery item should be within the following limits:

$$S_{nnp} \leq S_c + \frac{\Delta S_{gk} W_n - E_n \Delta K}{1 + E_n + E_n p} \text{ rub/unit}, \quad (3.12)$$

and the wholesale-release price

$$\frac{C_c}{p+1} - \frac{C_n}{p+1} + \Delta S_{gk} W_n \geq E_n \Delta K + E_n C_n - E_n C_c.$$

Following transformation the inequality will assume the form

$$C_{nnp} \leq S_c (1 + p) + \frac{(1 + p) (\Delta S_{\partial K} W_n - E_n \Delta K)}{1 + E_n + E_n p} \quad \text{rub/unit} \quad (3.13)$$

or

$$C_{nnp} \leq C_c + \frac{(1 + p) (\Delta S_{\partial K} W_n - E_n \Delta K)}{1 + E_n + E_n p} \quad \text{rub/unit.} \quad (3.14)$$

In those cases where money for capital investment is allocated from the new equipment fund, and the latter is funded through a special item in non-production expenditures (see page 94), that is,

$$\Delta K = 0,$$

$$S_{nnp} \leq S_c + \frac{\Delta S_{\partial K} W_n}{1 + E_n + E_n p} \quad \text{rub/unit,} \quad (3.15)$$

and

$$C_{nnp} \leq S_c (1 + p) + \frac{(1 + p) \Delta S_{\partial K} W_n}{1 + E_n + E_n p} \quad \text{rub/unit,} \quad (3.16)$$

or

$$C_{nnp} \leq C_c + \frac{(1 + p) \Delta S_{\partial K} W_n}{1 + E_n + E_n p} \quad \text{rub/unit.} \quad (3.17)$$

The above formulas (3.12)-(3.17) make it possible to find economically allowable maximum production cost and wholesale-release price values for the newly-designed piece of equipment, whereby in the production area production profitability does not diminish in comparison with the old equipment, and in the area of operation a substantial portion of the savings achieved by replacing the old with the new equipment remains.<sup>3</sup>

Let us turn to the example examined on page 129 and find maximum production cost and wholesale-release price under the condition that savings are divided between manufacturer and purchaser.

When  $C_0=500$  rub/unit ( $S_0=455$  rub/unit);  $\Delta S_{ek}=S_{ek_0}-S_{ek_n}=0.2$  unit of productivity;  $W_0=500$  units of productivity per year;  $W_n=550$  units of productivity per year;  $E_s=0.2$  1/year;  $\Delta K=50$  rub/unit;  $p_0=0.1$  with formulas (3.12) and (3.14) we obtain:

$$S_{nnp} \leq 455 + \frac{0.2 \cdot 550 - 0.2 \cdot 50}{1 + 0.2 + 0.2 \cdot 0.1};$$

$$S_{nnp} \leq 537 \quad \text{rub/unit,}$$

$$C_{nnp} \leq 500 + \frac{(1 + 0.1) (0.2 \cdot 550 - 0.2 \cdot 50)}{1 + 0.2 + 0.2 \cdot 0.1}.$$

$$C_{nnp} \leq 590 \quad \text{rub/unit.}$$

Profitability thereby is

$$p_{\kappa} = \frac{590}{527} - 1 = 0,1,$$

that is, remains at the previous level.

If funds for capital investment are allocated from the new equipment fund [second instance, formulas (3.15) and (3.17)], then

$$\begin{aligned} S_{\kappa np} &\leq 455 + \frac{0,2 \cdot 550}{1 + 0,2 + 0,2 \cdot 0,1}; \\ S_{\kappa np} &\leq 545 \text{ rub/unit,} \\ C_{\kappa np} &\leq 500 + \frac{(1 + 0,1) 0,2 \cdot 550}{1 + 0,2 + 0,2 \cdot 0,1}; \\ C_{\kappa np} &\leq 599 \text{ rub/unit.} \end{aligned}$$

Profitability thereby is

$$p_{\kappa} = \frac{599}{545} - 1 = 0,1.$$

As is evident from this example, in order to retain profitability of manufacture of machinery of a given type it is necessary to assign to the plant part of the annual savings obtained in operation.

In the given case, from 110 rubles annual savings ( $550 \cdot 0,2$ ) in the first example, we must take

$$(C_{\kappa np} - C_c) E_{\kappa} = (599 - 500) 0,2 = 18 \text{ rubles,}$$

that is, 16.7%. The purchaser obtains savings of 92 rubles per year from total savings of 110 rubles per year from the purchase of each machine.

Maximum allowable increase in the value of productive assets when putting a new item into production in place of an old item, whereby the previous level of production profitability as a whole will be secured, can be determined as follows.

If we designate with  $p_n$  the level of planned enterprise production profitability, then in putting into production a new item in place of an old item, there should be observed as a minimum the ratio

$$\begin{aligned} p_n &= \frac{(C_{\kappa np} - S_{\kappa np}) N_{zo\partial\kappa} + \sum_{i=1}^{n-1} P_{pi} N_{zo\partial i}}{V_{\kappa}} = \\ &= \frac{(C_c - S_c) N_{zo\partial c} + \sum_{i=1}^{n-1} P_{pi} N_{zo\partial i}}{V_c}, \end{aligned} \quad (3.18)$$

where  $V_n$  -- average productive assets value (fixed assets and working capital) under conditions of production of a new machinery item, in rubles;  $V_o$  -- average value of productive assets in producing the old machinery item;  $N_{yr_n}$ ;  $N_{yr_o}$  -- annual production schedule for new and old machinery items respectively, units;  $n-1$  -- remaining list of items produced by the plant;  $P_{pi}$  -- profit on each item of the remaining product list;  $N_{yr_i}$  -- annual production schedule for each item on the remaining product list.

Then

$$V_n = \frac{(C_{n_{np}} - S_{n_{np}}) N_{zo\partial_n} + \sum_{i=1}^{n-1} P_{pi} N_{zo\partial_i}}{(C_c - S_c) N_{zo\partial_c} + \sum_{i=1}^{n-1} P_{pi} N_{zo\partial_i}} V_c \text{ rub.} \quad (3.19)$$

If in the above example productive assets totaled 20 million rubles with manufacture of old machinery items, annual production  $N_{yr_n} = N_{yr_o} = 1,000$  machines, while profit on the remaining product list

$$\sum_{i=1}^{n-1} P_{pi} \times N_{zo\partial_i} = 100,000 \text{ rubles per year,}$$

then the maximum value of productive assets in producing new machinery will be:

$$V_n = \frac{(590 - 537) 1000 + 100\,000}{(500 - 455) 1000 + 100\,000} 20\,000\,000 = 21\,100\,000 \text{ rub.},$$

that is, productive assets can be increased by 1.1 million rubles without diminishing production profitability.

In the second instance  $V_n$  will be

$$V_n = \frac{(599 - 545) 1000 + 100\,000}{(500 - 455) 1000 + 100\,000} 20\,000\,000 = 21\,240\,000 \text{ rub.},$$

that is, an assets increase of 1.24 million rubles can be allowed.

Under conditions of single-list production

$$\sum_{i=1}^{n-1} P_{pi} N_{zo\partial_i} = 0$$

[see formula (3.19)]; then the maximum possible increase in value of productive assets, securing the former level of production profitability, can be obtained with formula

$$V_{\mu} = \frac{(C_{\mu np} - S_{\mu np}) N_{200\mu}}{(C_c - S_c) N_{200c}} V_c \text{ rub.} \quad (3.20)$$

If productive assets with the manufacture of old machinery items in the first example above totaled 20 million rubles, the maximum value of productive assets in producing new machinery items (when  $N_{yr_n} = N_{yr_o}$ ) will equal

$$V_{\mu} = \frac{590 - 537}{500 - 455} 20 = 23,6 \text{ rub.},$$

that is, productive assets can be increased by a maximum of 3.6 million rubles without diminishing production profitability.

In the second instance

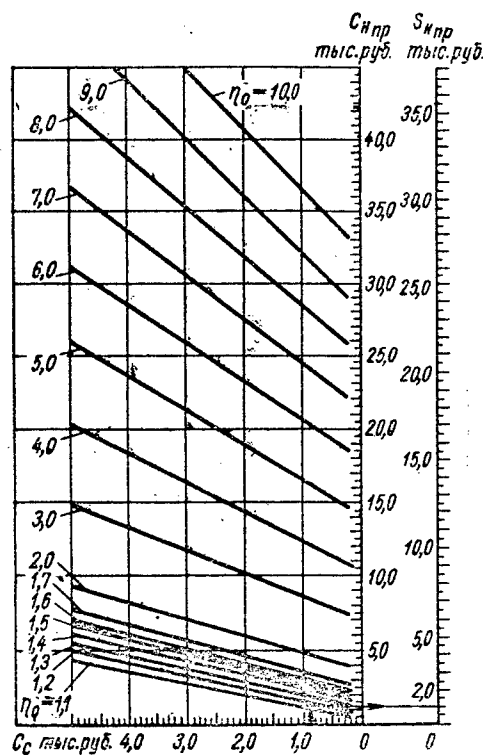
$$V_{\mu} = \frac{599 - 545}{500 - 455} 20 = 24 \text{ rub.},$$

that is, an increase in assets by 4 million rubles can be permitted.

In order to determine the maximum wholesale-release price and production cost, auxiliary reference tables and nomograms can be elaborated, which substantially speed up calculations. An example of such a nomogram for determining maximum allowable outlays on new types of universal machine tools [12] is contained in Figure 3.1.

Figure 3.1. Nomogram for Determining Maximum Allowable Outlays on New Types of Universal Machine Tools

Key to figure:  $C_o$  -- wholesale-release price of replaced model in rubles per unit;  $C_{np}$  -- maximum wholesale-release price on improved-quality item;  $\eta_0$  -- degree of increase in equipment productivity, times;  $S_{np}$  -- maximum production cost of improved-quality item (when  $p=0.2$ )



Concluding our analysis of calculated quantities, machine production cost  $S_n$  and wholesale-release price  $C_n$ , obtained by the methods described in chapters 1 and 2, should be compared with the values of maximum-allowable production cost  $S_{nnp}$  and price  $C_{nnp}$ , calculated with formulas (3.12) and (3.14) or (3.15) and (3.17).

Under conditions where  $S_n < S_{nnp}$ , while  $C_n = C_{nnp}$ , the plant will have a higher profitability than on the previously-produced machinery item, and therefore with a substantial difference in the production cost of the newly-designed machinery item  $S_n$  and its maximum value  $S_{nnp}$ , its price level  $C_n$  may be reduced in comparison with the maximum price value  $C_{nnp}$  obtained with formulas (3.14) or (3.17). The degree of this reduction should be such as to provide incentive for design organizations and manufacturers not to bring a machine's  $S_n$  and  $C_n$  close to  $S_{nnp}$  and  $C_{nnp}$ , but on the contrary, to achieve substantial differences from maximum values (on the downward side, of course).

Under conditions where calculated value  $C_n$  differs more or less substantially (on the downward side) from specified maximum value  $C_{nnp}$ , it is advisable when putting a machinery item into production to establish one or two levels of provisional wholesale-release prices.

Initially, after series production starts up (as a rule for 6 months to a year) a temporary wholesale-release price can be set at level  $C_{nnp}$  independent of calculated value  $C_n$ ; this wholesale-release price level will ensure sufficient effectiveness of machine utilization in the operation area, and will ensure the manufacturing plant an adequate level of production profitability with a production cost close to  $S_{nnp}$  (see example on page 119) or at a level between  $C_{nnp}$  and  $C'_{nnp}$  if the actual cost of producing the machinery item is initially greater than  $S_{nnp}$  and in connection with this it is impossible to secure the specified production profitability level with a price at the level  $C_{nnp}$ ; this naturally will temporarily result in a certain decrease in machinery utilization effectiveness in the area of operation (or upon establishment of price at the level  $C'_{nnp}$  the absence of economic effect within the bounds of the standard term of recovery of investment).

A second wholesale-release price level can be established between limits  $C_n$  and  $C_{nnp}$  in conformity with actual production cost, if the latter has not yet reached calculated level  $S_n$  or at level  $C_n$ , if the calculated production cost  $S_n$  is achieved by the second year of production.

However, in order to provide the manufacturer with material incentive quickly to achieve the calculated production cost on a new machinery item  $S_n$ , in establishing prices one should elaborate a progressive scale of increasing profitability on the given item. Therefore we can suggest the following procedure for establishing temporary wholesale-release prices for the initial years of manufacture. Table 3.2 contains a variant of establishment of wholesale-release prices with the following figures: production cost of machinery item currently in production  $S_0 = 455$  rubles per unit; wholesale-release price of machinery item currently in production  $C_0 = 500$  rubles per unit;

annual productivity of currently-produced machinery item  $W_0=500$  units of productivity per year; calculated production cost of new machinery item  $S_n=500$  rubles per unit; calculated wholesale-release price of new machinery item  $C_n=550$  rubles per unit; new machinery item annual productivity  $W_n=550$  units of productivity per year; specific additional capital investment on the new machinery item  $\Delta K=50$  rubles per unit; standard economic effectiveness factor  $E_s=0.2$  l/yr; planned profitability of the currently-manufactured item and calculated profitability of the new machinery item,  $p=0.1$ .

Table 3.2. Establishment of Wholesale-Release Price on a Newly-Designed Machinery Item

№ по пор.	12 Параметры	13 Условное обозначение	14 Продолжительность серийного выпуска в годах			16 Примечание
			0—0.5	0.5—1.5	1.5 и более	
1	Экономия на эксплуатационных расходах в руб/ед. производительности . . . . .	$\Delta S_{эк}$	0.10	0.15	0.20	17 Экономия различается из-за предусмотримого изменения оптово-отпускной цены, что отражается на величине амортизационных отчислений
2	Ожидаемая фактическая себестоимость новой машины в руб/шт. . . . .	$S_{нф}$	650	550	500	18 Определяется по статистическим графикам снижения себестоимости продукции по годам выпуска исходя из запланированной себестоимости новой машины (500 руб.)
3	Предельная себестоимость новой машины в руб/шт. . . . .	$S'_{нпр}$	750	875	1000	По формуле (3.5) 19
4	Предельная оптово-отпускная цена новой машины в руб/шт. . . . .	$C'_{нпр}$	825	962	1100	По формуле (3.4) 19

Table 3.2 (cont'd)

№ по пор.	12 Параметры	13 Условное обозначение	14 Продолжительность серийного выпуска в годах			16 Примечание
			0-0.5	0.5-1.5	1.5 и более	
5	Экономически допустимая предельная себестоимость новой машины в руб/шт. . . . .	$S_{нпр}$	492	514	537	По формуле (3.12) 19
6	Экономически допустимая предельная отпускная цена новой машины в руб/шт. . . . .	$C_{нпр}$	541	565	590	По формуле (3.14) 19
7	Устанавливаемая заводо-отпусная цена новой машины в руб/шт.	$C_{зав}$	715	617	572	20 Временная оптовая цена 715 руб. на первые полгода установлена для сохранения нормального уровня рентабельности (0,1) исходя из ожидаемой фактической себестоимости (650 руб.). В остальных графах уровень рентабельности повышается по принятому в данном примере значению прогрессии 1,2 (см. п. 8)

Table 3.2 (cont'd)

№ по пор.	12 Параметры	13 условное обозначение	14 Продолжительность серийного выпуска в годах			16 Примечание
			0-0,5	0,5-1,5	1,5 и более	
8	Установленная рентабельность по новой машине . . . . .	$P_{зад}$	0,1	0,12	0,145	—
9	Годовая экономия у потребителя на одну машину в руб. . . . .	—	55	82,5	110	21 Произведение п. 1 на годовую производительность новой машины
10	Годовая экономия у потребителя, остающаяся заводу-изготовителю, в руб. . . . .	—	43	23,4	14,4	$(C_{нзад} - C_c) E_n$
11	% годовой экономии у потребителя, выделяемой заводу-изготовителю . . . . .	—	78,2	28,4	13,1	—

Key to table: 1 -- savings on operating costs, in rubles per unit of productivity; 2 -- anticipated actual cost of producing new machinery item, in rubles per unit; 3 -- maximum cost of producing new machinery item, rubles per unit; 4 -- maximum wholesale-release price on new item, rubles per unit; 5 -- economically allowable maximum production cost of new item, rubles per unit; 6 -- economically allowable maximum wholesale-release price of new item, rubles per unit; 7 -- wholesale-release price on new item established for the plant, rubles per unit; 8 -- established profitability on a new item;

(Key to Table 3.2 continued from preceding page) 9 -- annual savings by purchaser per unit, rubles; 10 -- annual purchaser savings going to manufacturer; 11 -- percentage of annual savings for purchaser allocated to manufacturing plant; 12 -- parameters; 13 -- symbols; 14 -- duration of series production, years; 15 -- and longer; 16 -- comments; 17 -- savings differ due to specified change in wholesale-release price, which is reflected in size of depreciation allowance; 18 -- determined from statistical graphs of decrease in item production cost from year to year, proceeding from planned production cost of new machinery item (500 rubles); 19 -- see formula; 20 -- temporary wholesale price 715 rubles for the first 6 months, established to retain standard level of profitability (0.1), proceeding from anticipated actual production cost (650 rubles). In the other columns the level of profitability increases by common progression ratio 1.2, adopted in the given example (see 8); 21 -- product of number 1 and annual productivity of new machinery item

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As is evident from the table, the proposed procedure of establishing a whole-sale-release price not only offers the manufacturing plant incentive to adopt new equipment, since it retains the previous level of profitability from the very initiation of series manufacture of the new machinery item, but also provides incentive rapidly to achieve plan-specified production cost. Wholesale price for the first 6 months of series production is established at  $C'_{nnp}$  (when  $C'_{nnp}=825$  rubles per unit, the temporary wholesale price is  $C_{nzad}=715$  rubles per unit), which ensures recovery of investment within the standard period of time. After 18 months the wholesale price ( $C_{nzad}=572$  rubles per unit) is lower than the economically allowable maximum price ( $C_{nnp}=590$  rubles per unit), but nevertheless it ensures a substantial increase in profitability of machinery manufacture.

Even with observance of plan-specified production setup timetables, determined on the basis of statistical data on prior-manufactured machinery of a similar kind (reduction of production cost with each year in production or after so many units produced from the beginning of production), machinery production profitability increases. If a plant sets up full production of a new machinery item in a shorter period of time, reaching planned (calculated) production cost  $S_n=500$  rubles not in one and half years, let us say, but after 6 months, production profitability on the new machinery item will reach a level of 0.23 in 6 months, that is, will significantly exceed the level set for the second year in production.

Of course during practical utilization of the proposed method there may be substantial corrections in individual elements of the calculation (gradation of established prices by year, geometric progression ratio in establishing a level of profitability, etc). This will be determined in large measure by branch features, size of production run and other factors. The main thing is that this method makes it possible to retain and even to increase production profitability with the adoption of new equipment, ensuring thereby adequate economic effectiveness in the area of operation (particularly when the manufacturer rapidly reaches the economically allowable maximum production cost  $S_{nnp}$ ). This is particularly important under conditions of

changeover by all plants to the new principles of economic management specified by the September (1965) CPSU Central Committee Plenum and the 23d CPSU Congress.

Figure 3.2 contains a general diagram of a comprehensive analysis of machine economic parameters, production cost, maximum production cost and price. The double lines in the diagram indicate feedback -- the need to make certain decisions in relation to analysis results.

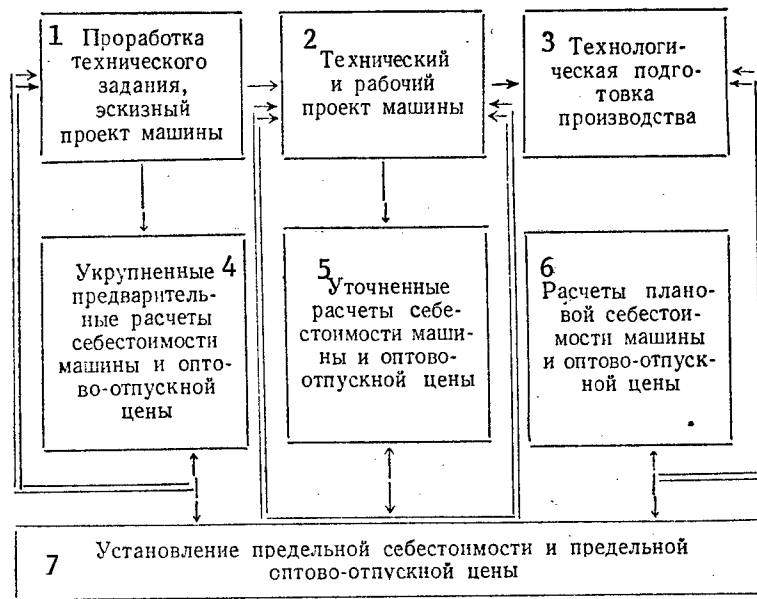


Figure 3.2. Diagram of Comprehensive Analysis of Machine Parameters, Production Cost, Maximum Production Cost and Price During Preproduction Design and Engineering

Key to figure: 1 -- preparation of preliminary design, preliminary drawings; 2 -- preliminary and detailed engineering; 3 -- preproduction engineering; 4 -- consolidated preliminary calculations of machinery production cost and wholesale-release price; 5 -- refined calculations of machinery production cost and wholesale-release price; 6 -- calculations of machinery planned production cost and wholesale-release price; 7 -- establishment of maximum production cost and maximum wholesale-release price

We should note that in establishing a wholesale-release price on a newly-designed machinery item, a number of other technical-economic factors should also be analyzed. In particular, it is of considerable significance to the manufacturer to determine what percentage share of machinery production cost is represented by purchased semimanufactures, finished items, assemblies

and parts obtained on a cooperative manufacture basis from other plants. At some plants the share of cooperative-manufactured items ranges from 50 to 80% of production cost, which significantly reduces a plant's capability to increase production profitability by finding and utilizing in-plant reserve potential for reducing manufacturing costs. One should bear in mind thereby that some component items obtained on the basis of cooperative manufacture may carry an overstated wholesale-release price and bring the supplier plant high profits, while increasing manufacturing costs at the customer plant.

At the same time a broadening of cooperative manufacture with unchanged scale of production leads to a decrease in the cost of productive assets required by the plant, which increases production profitability.

Also of importance in establishing a wholesale-release price are other significant factors, but even an analysis of the above factors presents considerable difficulties and requires separate investigation.

#### 4. Ways to Reduce the Labor Requirements of Calculating Production Costs

Gradual refinement of calculations performed at the stages of preproduction design, as input information is accumulated, substantially increases the labor required.

In fact, if at the preliminary planning stage and during preparation of preliminary sketches one is limited to a consolidated calculation for the new machinery item as a whole, utilizing one or two calculation relations for this purpose, at the preliminary engineering stage, with the unit-by-unit (or assembly-by-assembly) method of calculation the number of these relations will frequently run into the dozens and hundreds, while at the detailed engineering stage, with the part-by-part method of calculation, there may be several thousand or tens of thousands. This will cause significant difficulties in the practical employment of the suggested calculation methods.

Collection, processing and classification of a large quantity of statistical material are essential in order to obtain calculation formulas on machinery items, units, assemblies, and parts. This task can be handled only by large staffs of branch scientific research institutes and design organizations, with extensive employment of information encoding methods, computer hardware, etc. Employment of numerous formulas for refined calculations on the cost of producing designed parts, assemblies and units as well as determination of machinery production cost on the basis of the performed calculations constitute extremely laborious jobs which are scarcely within the capability of the small number of economists employed by design organizations and industrial plants.

These factors lead to the necessity of elaborating a well-balanced classification of parts, assemblies, units and machinery items on the basis of design-process features and the construction of calculation formulas applicable to

classes, first and foremost for parts, assemblies and units of interbranch application -- bearings, gears, clutches, motors, reduction gears, etc, on which there is available considerable statistical material, making it possible to obtain standard calculation formulas. Design features, manufacturing process and organizational conditions of production, and operation-maintenance requirements could be considered separate components or factors in these formulas. For such formulas it is necessary to elaborate convenient reference tables and nomograms, making it possible quickly to obtain the values of individual components and factors of the calculation formula.

If serious difficulties are encountered in elaborating reliable calculated relations for parts, assemblies and units of narrow-branch application due to a deficiency of input data, making it impossible to apply modern methods of mathematical statistics and probability theory, then for items of interbranch application the greatest difficulty evidently consists in collecting factual data on materials requirements, labor requirements and cost of manufacture, and in classification of materials on the basis of the methods of already-performed calculations and selection of optimal ones. This job is too much for individual investigators even with localization of analysis on a single type of item. Gear reducers, for example, are manufactured by hundreds of plants of various branches (including in this class transmissions for cars, trucks, tractors, machine tool gearboxes, etc); calculations on these, including technical-economic calculations, are performed by numerous organizations, scientific research institutes, special design offices, and plant facilities.

This work should be performed in a centralized manner, by a large scientific research institute of economic specialization with the extensive involvement of engineer-technician personnel -- designers and process engineers. It is to the benefit of our entire national economy, particularly now, when a major campaign is under way to regulate prices, to bring them closer to value, with enormous importance attached to producing machinery with high technical-economic indices both in production and in operation, when planning and design organizations and industrial plants should possess precise knowledge in advance, long before initiation of production, of the economic effect to be obtained from putting new machinery into production.

The following is necessary in order to perform precise calculations of technical-economic indices and to reduce their labor requirements: to classify parts, assemblies, units, and machinery by design-process and operation features; to systematize all statistical technical-economic materials on each class and reference materials on methods of calculating technical-economic indices; to elaborate standard calculation formulas for determining materials requirements, labor requirements and production cost applicable to each class of parts, assemblies, units, and machines, for their utilization at various stages of preproduction; to prepare on each class reference tables, nomograms and graphs which make it possible quickly to determine the values of individual components and coefficients of a calculation formula for specific design features, process, organizational and operational conditions; to

train personnel of plant planning-economic, design and process engineering divisions, design organization personnel, and students at technical and engineering-economic higher educational institutions and secondary technical schools methods of calculating production cost in designing machinery; extensively to utilize modern high-speed computer hardware for establishing a standards base and performance of calculations of the cost of producing machinery in the design stages.

Analysis of calculated production cost and wholesale-release price together with analysis of allowable (maximum) production and wholesale-release price should be performed at all stages of preproduction, with designers mobilized to obtain high technical-economic indices of new machinery designs.

The economic reform carried out in this country on the basis of the resolutions of the September (1965) CPSU Central Committee Plenum and the 23d CPSU Congress offers enterprises incentive to achieve optimal economic indices in their activities and to improve production profitability. This will unquestionably be promoted by establishment during the design process of economically substantiated production cost and wholesale-release price of new-design machinery.

#### FOOTNOTES

1. In this study we do not examine the method of determining the effectiveness of new equipment but only analyze possible methods of calculating production cost, which is a component part of technical-economic effectiveness analysis. The method proper is examined in detail in a number of studies [1, 5, 11, 12].
2. Machinery production profitability  $p$  should not be confused with the term level of profitability of an enterprise's production activities, which is defined, as we know, as the ratio of profit to the average value of productive assets.
3. We are dealing here only with establishment of an economically substantiated maximum machinery price, not with any limit to enterprise profitability. With economical production it is possible to achieve considerably higher actual enterprise profitability. Proceeding from the requirements of economic policy, government organizations can establish different correlations in distribution of savings between manufacturer and customers in order to increase production profitability at a given plant.

# APPENDICES

## Appendix 1

List of Price Lists, Effective 1 July 1967,  
on Materials, Purchased Items and Installation  
Jobs Required for Computing the Cost of Designed  
Machinery

Материалы, покупные изделия, виды работ 1	№ преискурнга 2
Оптовые цены 3	
Чугун и ферросплавы . 4 . . . . .	01-01
Сталь обыкновенного качества .5. . . . .	01-02
Качественная сталь . 6 . . . . .	01-03
Трубы стальные и чугунные . . 7 . . . . .	01-04
Металлоизделия промышленного назначения .8..	01-05
Лом и отходы черных металлов (заготовительные и сбытовые цены) . 9 . . . . .	01-08
Цветные металлы, сплавы и порошки . .10. . . .	02-01
Твердые сплавы и изделия из них . . . . .11. .	02-03
Электродная продукция . . . . .12. . . . .	02-04
Прокатно-тянутые и прессованные изделия из цветных металлов и сплавов . . . . .13 . . . .	02-06
Нефтепродукты (оптовые цены промышленности)14	04-02
Природный газ, попутный нефтяной газ, газ от переработки нефти, искусственный газ, газ коксовый, газ доменный и газ от химической переработки топлива (оптовые цены промышленности и оптовые цены предприятия) . . . . .15 . . . . .	04-03
Химическая продукция . . . . .16. . . . .	05-01
Синтетические красители и промежуточные продукты для красителей . . . . .17. . . . .	05-02
Изделия и детали для автотракторной промышленности и трубы из пластических масс .18. . .	05-03
Лакокрасочные материалы . .19. . . . .	05-04
Ленты конвейерные и ремни прорезиненные .20. . .	05-06
Продукция шинной промышленности 21. . . . .	05-05
Резиновые технические детали и изделия 22. . .	05-08
Химические реактивы и препараты . . . . .23 .	05-11

Appendix 1 (cont'd)

1	Материалы, покупные изделия, виды работ	2	№ прейскуранта
24	Продукция шинной промышленности (единые оптовые цены) . . . . .	05-14	
25	Цемент . . . . .	06-01	
26	Изделия из стекла и стеклянного волокна . . . . .	06-02	
27	Сборные железобетонные изделия . . . . .	06-08	
28	Металлическая тара . . . . .	07-26	
29	Тарифы на электрическую и тепловую энергию, отпускаемую энергосистемами и электростанциями Министерства энергетики и электрификации СССР .	09-01	
30	Тарифы на грузовые железнодорожные перевозки (Тарифное руководство № 1 Министерства путей сообщения) . . . . .	10-01	
31	Тарифы на перевозки грузов автомобильным транспортом . . . . .	13-01-01 (1964 г.)	
32	Машины электрические средней и малой мощности . . . . .	15-01	
33	Машины электрические большой мощности, турбогенераторы, гидрогенераторы и передвижные электростанции . . . . .	15-02	
34	Аппаратура электрическая высоковольтная . . . . .	15-03	
35	Аппаратура электрическая низковольтная. Часть I.		
36	Аппаратура электрическая низковольтная. Часть II.		
37	Комплектные устройства . . . . .	15-04	
38	Трансформаторы, подстанции трансформаторные комплектные, реакторы и преобразователи силовые. Часть I. Трансформаторы, подстанции трансформаторные комплектные. Часть II. Преобразователи силовые и реакторы бетонные . . . . .	15-05	
39	Оборудование электросварочное, преобразователи высокой частоты для плавки и закалки металлов и оборудование для газовой сварки . . . . .	15-06	
40	Кабельные изделия . . . . .	15-09	
41	Электроизоляционные изделия. Часть I. Электроизоляционные изделия. Часть II. Электроизоляционные керамические изделия . . . . .	15-10	
42	Аккумуляторы электрические, батареи и элементы гальванические . . . . .	15-11	
43	Аппаратура радиосвязи и радиодетали общего применения . . . . .	16-01	
44	Электровакуумные и полупроводниковые приборы и светотехнические изделия . . . . .	16-03	
45	Аппаратура проводной связи . . . . .	16-02	
46	Приборы электроизмерительные общего применения . . . . .	17-01	
47	Приборы радиотехнические измерительные общего применения . . . . .	17-02	

Appendix 1 (cont'd)

1	Материалы, покупные изделия, виды работ	2 № преysкуранта
48	Приборы и машины для испытания материалов, измерения механических величин и приборы времени . . . . .	17-03
49	Приборы для контроля и регулирования температуры, расхода, уровня, давления, состава и состояния веществ в производственных процессах . .	17-04
50	Средства вычислительной техники . . . . .	17-08
51	Станки металлорежущие . . . . .	18-01
52	Оборудование деревообрабатывающее . . . . .	18-02
53	Машины кузнечно-прессовые . . . . .	18-03
54	Оборудование для литейных цехов . . . . .	18-04
55	Инструмент и измерительные приборы. Часть I. Режущий инструмент. Часть II. Режущий инструмент зуборезный и протяжной. Часть III. Измерительный инструмент и измерительные приборы. Часть IV. Напильники, дереворежущий, слесарно-монтажный инструмент и инструмент разного назначения . . . . .	18-05
56	Инструмент нестандартизированный: измерительный, режущий, строительный, слесарно-монтажный и прочий . . . . .	18-05-01 (1963г.)
57	Материалы абразивные, инструмент абразивный и шкурка шлифовальная . . . . .	18-06
58	Алмазные порошки и алмазный инструмент из природных и синтетических алмазов . . . . .	18-07
59	Гидроаппаратура, пневмоаппаратура и аппаратура для смазки . . . . .	18-08
60	Котлы, турбины, турбоустановки и машины паровые . . . . .	19-04
61	Котельно-турбинное вспомогательное оборудование . . . . .	19-05
62	Оборудование грузоподъемное транспортирующее. Часть I. Краны и погрузочно-разгрузочное оборудование. Часть II. Лебедки и цепи. Часть III. Транспортирующее оборудование . . . . .	19-06
63	Промышленные печи и нагревательные установки . . . . .	19-07
64	Редукторы и муфты соединительные . . . . .	19-08
65	Подвижной железнодорожный состав . . . . .	20-01
66	Суда морские, озерные и речные самоходные (с двигателем мощностью свыше 400 л. с.) и несамоходные (грузоподъемностью свыше 1000 т), судовые механизмы и оборудование. Часть I. Суда морские, озерные и речные. Часть II. Судовые механизмы и оборудование . . . . .	20-02
67	Двигатели внутреннего сгорания, дизель-генераторы и газо-мотокомпрессоры . . . . .	20-03

Appendix 1 (cont'd)

	1 Материалы, покупные изделия, виды работ	2 № преysкуранта
68	Суда морские, озерные и речные самоходные (с двигателем мощностью до 400 л. с.), несамоходные (грузоподъемностью до 1000 т), судовые механизмы, оборудование и др. . . . .	20-04
69	Автомобили, автобусы, троллейбусы, тракторы, прицепы, грузовые мотороллеры, погрузчики, электрокары . . . . .	21-01
70	Подшипники шариковые, роликовые и шарнирные . . . . .	21-02
71	Машины сельскохозяйственные . . . . .	21-03
72	Электрооборудование, приборы, топливная аппаратура и запасные части к ним для автомобилей, мотоциклов, тракторов и сельскохозяйственных машин . . . . .	21-04
73	Электрооборудование, приборы, топливная аппаратура и запасные части к ним для автомобилей, тракторов и сельскохозяйственных машин (единицы оптовые цены) . . . . .	21-07A
74	Машины и оборудование строительное и оборудование торфяное . . . . .	22-01
75	Оборудование дробильно-размольное . . . . .	22-02
76	Инструмент строительно-дорожный . . . . .	22-04
77	Насосы . . . . .	23-01
78	Оборудование холодильное и компрессорное, вакуум-насосы, аппараты для производства кислорода и продуктов разделения воздуха, оборудование для хранения газов . . . . .	23-02
79	Оборудование химическое. Часть I. Стандартизированное химическое оборудование. Часть II. Нефтехимическая аппаратура . . . . .	23-03
80	Оборудование полиграфическое и копировальномножительное . . . . .	23-06
81	Арматура трубопроводная промышленная и судовая. Часть I. Арматура трубопроводная промышленная. Часть II. Арматура трубопроводная судовая . . . . .	23-07
82	Оборудование вентиляционное и для кондиционирования воздуха . . . . .	23-08
83	Оборудование для очистки воздуха и промышленных газов . . . . .	23-09
84	Фланцы, арматура и вспомогательные изделия, приборы и оборудование для трубопроводов . . . . .	23-10
85	Сильфоны . . . . .	23-11
86	Оборудование противопожарное и запасные части . . . . .	24-02-01 (1963г.)
87	Нормали к автомобилям и тракторам . . . . .	24-11

## Appendix 1 (cont'd)

1	Материалы, покупные изделия, виды работ	2 № прейскуранта
88	Изделия (детали и узлы) для систем отопления, вентиляции и водоснабжения, канализации и газоснабжения . . . . .	24-15
89	Рукава металлические, валы гибкие, плетенки и другие металлорукавные изделия . . . . .	24-16
90	Литье, поковки и горячие штамповки . . . . .	25-01
91	Запасные части к электрооборудованию . . . . .	27-01
92	Запасные части к аппаратуре проводной связи . . . . .	27-02
93	Запасные части к приборам . . . . .	27-03
94	Запасные части и нормалн к станкам металлообрабатывающим . . . . .	27-04
95	Запасные части к деревообрабатывающему оборудованию . . . . .	27-05
96	Запасные части к оборудованию кузнечно-прессовому и литейному . . . . .	27-06
97	Запасные части к автомобилям, автобусам, автопогрузчикам, прицепах и троллейбусам . . . . .	27-07
98	Запасные части к тракторам . . . . .	27-08
99	Запасные части к сельскохозяйственным машинам . . . . .	27-09
100	Запасные части к тракторам (единые оптовые цены) . . . . .	27-11A
101	Запасные части к оборудованию энергетическому . . . . .	27-15
102	Запасные части к двигателям внутреннего сгорания и агрегатам (кроме автомобильных и тракторных) . . . . .	27-18
103	Запасные части к строительным машинам и дробильно-размольному оборудованию. Часть I. Строительные машины. Часть II. Дробильно-размольное оборудование . . . . .	27-19
104	Запасные части к грузоподъемному и транспортирующему оборудованию . . . . .	27-22
105	Запасные части к насосам . . . . .	27-34
106	Запасные части к оборудованию холодильному, компрессорному, для получения и хранения газов, вентиляционному и газосварочному . . . . .	27-35
107	Запасные части к оборудованию химическому . . . . .	27-36
108	Запасные части к оборудованию для полиграфической промышленности . . . . .	27-37
109	Запасные части к арматуре трубопроводной промышленности, судовой и санитарно-технической . . . . .	27-38

Key to appendix: 1 -- materials, purchased items, type of job performed; 2 -- price list number; 3 -- wholesale prices; 4 -- pig iron and ferroalloys; 5 -- standard-quality steel; 6 -- grade steel; 7 -- steel and cast iron pipe; 8 -- industrial metal products; 9 -- scrap and ferrous metal waste (procurement and wholesale prices); 10 -- nonferrous metals, alloys and powders; 11 -- hard alloys and items of hard alloys; 12 -- electrodes; 13 -- rolled-drawn and pressworked items of nonferrous metals and alloys; 14 -- refined petroleum products (industrial wholesale prices); 15 -- natural gas, casing-head gas, gas from petroleum refining, synthetic gas, coke gas,

(Key to Appendix 1 on preceding pages, cont'd) blast-furnace gas, and gas from chemical fuel refining (industrial wholesale prices and enterprise wholesale prices); 16 -- chemical products; 17 -- synthetic dyes and intermediate products for dyes; 18 -- parts and items for the automotive and tractor industry and plastic pipe and tubes; 19 -- paints and varnishes; 20 -- conveyer belts and rubberized belts; 21 -- tire industry products; 22 -- industrial rubber parts and products; 23 -- chemical reagents and preparations; 24 -- tire industry products (uniform wholesale prices); 25 -- cement; 26 -- glass and fiberglass products; 27 -- prefabricated reinforced concrete products; 28 -- metal crating and packaging materials; 29 -- rates on electricity and heat produced in the power systems and at the power generating stations of the USSR Ministry of Power Engineering and Electrification; 30 -- rail freight rates (Ministry of Railroads Rate Guide No 1); 31 -- motor transport freight rates; 32 -- medium and low-power electrical machines; 33 -- high-power electrical machines, turbogenerators, hydrogenerators, and mobile electric power stations; 34 -- high-voltage electrical equipment; 35 -- low-voltage electrical equipment, Part I; 36 -- low-voltage electrical equipment, Part II; 37 -- complete equipment packages; 38 -- transformers, complete transformer substations, reactors and power converters. Part I. Transformers, complete transformer substations. Part II. Power converters and concrete reactors; 39 -- electric welding equipment, high-frequency converters for melting and hardening metals and gas welding equipment; 40 -- cable products; 41 -- electrical installation items. Part I. Electrical installation items. Part II. Ceramic electrical installation items; 42 -- storage batteries, batteries and voltaic cells; 43 -- radio communications equipment and general-application radio parts; 44 -- vacuum tubes, semiconductor devices and lighting products; 45 -- wire communications equipment; 46 -- general-application electrical measuring instruments; 47 -- general-application radio electronic testing equipment; 48 -- instruments and machines for testing materials, measuring mechanical values, and timing instruments; 49 -- instruments for monitoring and controlling temperature, flow, level, pressure, composition and state of substances in production processes; 50 -- computer equipment; 51 -- metal-cutting machine tools; 52 -- woodworking equipment; 53 -- press forging equipment; 54 -- foundry equipment; 55 -- tools and measuring instruments. Part I. Cutting tools. Part II. Gear-cutting and pull-broaching cutting tools. Part III. Measuring instruments and devices. Part IV. Files, wood-cutting, bench tools and miscellaneous tools; 56 -- nonstandard tools; measuring, cutting, construction, benchwork, etc; 57 -- abrasive materials, abrasive tools and sandpaper; 58 -- diamond powders and diamond tools of natural and synthetic diamonds; 59 -- hydraulic equipment, pneumatic equipment, and lubrication equipment; 60 -- boilers, turbines, turbine installations and steam engines; 61 -- auxiliary boiler and turbine equipment; 62 -- materials handling and transfer equipment. Part I. Cranes and loading-unloading equipment. Part II. Winches and chains. Part III. transfer equipment; 63 -- industrial furnaces and heating installations; 64 -- reduction gears and couplings; 65 -- rail rolling stock; 66 -- sea-going vessels, lake and river self-propelled (with engine exceeding 400 horsepower) and nonself-propelled (capacity greater than 1,000 tons) vessels, marine equipment and machinery. Part I. Sea-going, lake and river vessels.

(Key to Appendix 1 continued from preceding page) Part II. Marine equipment and machinery; 67 -- internal combustion engines, diesel generators and gas engine compressors; 68 -- sea-going, lake and river self-propelled (with engine up to 400 horsepower) and nonself-propelled (capacity up to 1,000 tons) vessels, marine equipment, machinery, etc; 69 -- passenger cars, trucks, buses, trolleybuses, tractors, trailers, motor scooter trucks, lift trucks, electric forklifts; 70 -- ball, roller and articulated bearings; 71 -- farm machinery; 72 -- electrical equipment, instruments, fuel equipment and spare parts for passenger cars, trucks, motorcycles, tractors, and farm machinery; 73 -- electrical equipment, instruments, fuel equipment and spare parts for cars, trucks, tractors and farm machinery (uniform wholesale prices); 74 -- construction machinery and equipment, peat equipment; 75 -- crushing and grinding equipment; 76 -- road construction tools; 77 -- pumps; 78 -- refrigeration and compressor equipment, vacuum pumps, equipment for producing oxygen and air separation products, equipment for storing gases; 79 -- chemical equipment. Part I. Standardized chemical equipment. Part II. Petrochemical equipment; 80 -- printing and copying equipment; 81 -- industrial and marine pipe fittings. Part I. Industrial pipe fittings. Part II. Marine pipe fittings; 82. Ventilation and air conditioning equipment; 83 -- air filtering and industrial gas scrubbing equipment; 84 -- flanges, fittings and auxiliary items, instruments and equipment for pipelines; 85 -- bellows; 86 -- fire-fighting equipment and spare parts; 87 -- passenger car, truck and tractor standards; 88 -- items (parts and assemblies) for heating, ventilating, water supply, sewage, gas supply systems; 89 -- metal hoses, flexible shafts, braided hoses and other metal hose products; 90 -- castings, forgings and hot stampings; 91 -- spare parts for electrical equipment; 92 -- spare parts for wire communications equipment; 93 -- spare parts for instruments; 94 -- spare parts and standards for metal-cutting machine tools; 95 -- spare parts for woodworking equipment; 96 -- spare parts for press forging and foundry equipment; 97 -- spare parts for cars, trucks, buses, lift trucks, trailers and trolleybuses; 98 -- spare parts for tractors; 99 -- spare parts for farm machinery; 100 -- spare parts for tractors (uniform wholesale prices); 101 -- spare parts for power equipment; 102 -- spare parts for internal combustion engines and equipment (other than automotive and tractor); 103 -- spare parts for construction equipment and crushing-grinding equipment. Part I. Construction machinery. Part II. Grinding-crushing equipment; 104 -- spare parts for materials handling and transfer equipment; 105 -- spare parts for pumps; 106 -- spare parts for refrigeration and compressor equipment, equipment for generating and storing gases, ventilation and gas welding equipment; 107 -- spare parts for chemical equipment; 108 -- spare parts for printing industry equipment; 109 -- spare parts for pipe and pipeline fittings, marine fittings and plumbing fixtures

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Appendix 2

Maximum Wholesale-Release Prices C on Pig Iron, Cast Irons  
(in rubles per ton)\*

Виды материала 1	C
<i>Чугун 2</i>	
3 Коксовый чугун ЛКО-ЛК5 . . . . .	78,9—59,5
4 Легированный чугун ЛХЧ1—ЛХЧ6 . . . .	104,0—65,0
5 Титановый чугун БТЛ1—БТЛ5 . . . . .	61,2
6 Титаномедистый чугун БТМЛЗ-БТМЛ5 . .	85,0—71,5
7 <i>Сталь углеродистая обыкновенная</i> (Ст. 1кп, Ст. 1сп. и др.)	
8 Круглая диаметром 9—250 мм . . . . .	110,0—76,4
9 Квадратная со стороной квадрата 9— 250 мм . . . . .	110,0—76,4
10 Полосовая толщиной 4—60 мм, шириной 12—200 мм . . . . .	110,0—78,1
11 Угловая равнобокая размером 20×20÷ ÷250 мм . . . . .	110,0—77,2
12 Угловая неравнобокая размером 25×16÷ ÷250×160 мм . . . . .	112,0—78,0
13 Балки двутавровые № 10—70 . . . . .	103,0—76,9
14 Швеллеры № 5—40 . . . . .	107,0—77,5
15 Тонколистовая толщиной до 3,9 мм . . . .	134,0—81,5
16 Толстолистовая толщиной 4—160 мм . . .	79,9—112,0
17 Широкополосная толщиной 5—60 мм при ширине 400—1050 мм . . . . .	101,0—72,6
18 <i>Сталь низколегированная</i> (14Г, 16ГС, 15ГФД и др.)	
19 Круглая и квадратная размером 9—250 мм	135,0—106,0
20 Полосовая шириной 12—200 мм, толщи- ной 4—60 мм . . . . .	136,0—109,0
11 Угловая равнобокая размером 20×20÷ ÷250×250 мм . . . . .	135,0—103,0
12 Угловая неравнобокая размером 25×16÷ ÷250×160 мм . . . . .	138,0—104,0
13 Балки двутавровые размером № 10—70 .	128,0—106,0
14 Швеллеры размером № 5—40 . . . . .	132,0—105,0
15 Тонколистовая толщиной до 3,9 мм . . . .	170,0—111,0
16 Толстолистовая толщиной 4—160 мм . . .	109,0—150,0
17 Широкополосная толщиной 5—60 мм, ши- риной 400—1050 мм . . . . .	128,0—103,0

Appendix 2 (cont'd)

	Виды материала 1	с
21	Сталь качественная (круглая и квадратная конструкционная 8—11 до 260—300 мм)	
22	Углеродистая качественная . . . . .	166,0—95,0
23	Легированная качественная . . . . .	359,0—111,0
24	Легированная высококачественная . . . . .	718,0—126,0
25	Рессорно-пружинная качественная . . . . .	264,0—122,0
26	Рессорно-пружинная высококачественная . . . . .	350,0—163,0
27	Инструментальная:	
28	углеродистая . . . . .	166,0—110,0
29	легированная . . . . .	1580,0—141,0
30	быстрорежущая . . . . .	5730,0—1720,0
31	Специальная (нержавеющая, жаропрочная)	3520,0—186,0
32	Тонколистовая толщиной (0,5—0,75) до 3,4 мм:	
28	углеродистая . . . . .	214,0—113,0
29	легированная . . . . .	1010,0—146,0
27	инструментальная . . . . .	4960,0—159,0
31	специальная . . . . .	3500,0—336,0
33	Толстолистовая толщиной (4—4,9) до (62—140) мм	
28	углеродистая . . . . .	153,0—112,0
29	легированная . . . . .	504,0—133,0
27	инструментальная . . . . .	3640,0—142,0
31	специальная . . . . .	2280,0—170,0
34	Широкополосная толщиной 4—60 мм, шириной 160—1050 мм	
28	углеродистая . . . . .	533,0—105,0
27	инструментальная . . . . .	160,0—132,0
* По прейскурантам оптовых цен № 01-01, 01-02, № 01-03, изданным в 1966 г. .		

Key to appendix: 1 -- types of material; 2 -- pig iron; 3 -- coke pig, LKO-LK5; 4 -- alloy cast iron, LKhCh1-LKhCh6; 5 -- titanium cast iron, BTL1-BTL5; 6 -- titanium-copper cast iron BTML-3-BTML5; 7 -- common carbon steel; 8 -- round, diameter; 9 -- square, side; 10 -- strip, thickness 4-60 mm, width 12-200 mm; 11 -- equal-leg angle; 12 -- unequal-leg angle; 13 -- I-beams; 14 -- channels; 15 -- sheet, up to 3.9 mm; 16 -- plate; 17 -- wide-strip, thickness 5-60 mm, width 400-1,050 mm; 18 -- low-alloy steel; 19 -- round and square; 20 -- strip, width 12-200 mm, thickness 4-60 mm;

(Key to Appendix 2, continued from preceding page) 21 -- high-grade steel (round and square structural, 8-11 to 260-300 mm); 22 -- fine carbon; 23 -- fine alloy; 24 -- high-grade alloy; 25 -- fine spring; 26 -- high-grade spring; 27 -- tool; 28 -- carbon; 29 -- alloy; 30 -- high-speed; 31 -- special (stainless, heat-resisting); 32 -- sheet, thickness (0.5-0.75) to 3.4 mm; 33 -- plate, thickness (4.49) to (62-160) mm; 34 -- plate, thickness 4-60 mm, width 160-1,050 mm; \* -- according to wholesale price lists numbers 01-01, 01-02, 01-03, published in 1966.

### Appendix 3

#### Wholesale Prices on Castings, in rubles per ton\*

1	Материал отливки 2														
	Серый чугун (ГОСТ 1412-54) СЧ 00, СЧ 12-28, СЧ 15-32, СЧ 18-36; 3					Высокопрочный чугун (ГОСТ 7293-54) ВЧ 45-0, ВЧ 50-1,5, ВЧ 60-2; 4					Углеродистая сталь (ГОСТ 977-65) 15Л, 20Л, 25Л, 30Л, 35Л, 40Л, 45Л, 50Л, 55Л; 5				
	Группа сложности 6														
Вес отливки в кг	7	8	9	10	Особо слож- ные	7	8	9	10	Особо слож- ные	7	8	9	10	Особо слож- ные
	Простые	Несложные	Средней сложности	Сложные		Простые	Несложные	Средней сложности	Сложные		Простые	Несложные	Средней сложности	Сложные	
12 До 0,2	265	300	345	400	460	380	435	500	570	650	310	370	435	510	595
От 0,2 до 0,5	250	285	330	385	445	365	420	485	555	635	300	360	425	500	585
» 0,5 » 1,0	235	270	315	370	425	350	405	470	540	620	280	335	400	470	550
» 1 » 3	210	245	290	340	395	315	365	430	500	560	255	310	370	440	515
» 3 » 10	185	220	265	315	370	265	315	375	440	480	230	285	340	405	480
» 10 » 20	170	205	245	295	345	250	285	330	385	435	210	260	315	380	455
» 20 » 50	160	190	230	280	330	235	260	320	375	410	190	240	295	355	425
» 50 » 200	145	175	215	260	310	215	245	290	340	395	175	220	270	330	400
» 200 » 500	130	160	195	240	290	200	225	275	320	355	165	210	260	315	385
» 500 » 1 000	125	155	190	230	275	195	215	265	310	335	155	200	250	305	370
» 1 000 » 3 000	120	145	180	220	265	185	205	245	280	325	150	190	235	290	350
» 3 000 » 10 000	115	135	165	200	240	180	200	240	275	315	145	180	220	270	330
» 10 000 и более	120	130	160	195	235	175	190	235	270	300	140	175	215	265	320

(17)

\* По прейскуранту оптовых цен 25-01, изданному в 1966 г.

\* По прейскуранту оптовых цен 25-01, изданному в 1966 г.

Appendix 3 (cont'd)

1		Материал отливки 2														
		14		15		16										
		Конструкционная легированная сталь (ГОСТ 7832-65) 30ХНМЛ, 40ХНТЛ		Алюминевые сплавы (ГОСТ 2685-63) АЛ-2, АЛ-4, АЛ-9		Медно-цинковые сплавы (ГОСТ 1019-47) ЛА67-25, ЛАМЖ 66-6-3-2, ЛАЖ 60-1-1Л, ЛК 80-3Л, ЛМЖС 53-2-2, ЛМЖ 55-3-1, ЛМЖ 52-4-1, Л62, ЛМЖ 58-2, ЛС 59-1Л										
Вес отливки в кг		Группа сложности 6														
		7	8	9	10	11	7	8	9	10	11	7	8	9	10	11
От 0,2 до 0,5		Простые	Несложные	Средней сложности	Сложные	Особо сложные	Простые	Несложные	Средней сложности	Сложные	Особо сложные	Простые	Несложные	Средней сложности	Сложные	Особо сложные
		550	645	765	905	1065	1260	1375	1505	1645	1805	1130	1155	1190	1230	1275
» 0,5 до 1,0		520	615	735	875	1035	1225	1340	1470	1610	1770	1120	1145	1180	1220	1265
» 1 до 3		485	580	700	840	990	1185	1300	1430	1570	1730	1110	1135	1170	1210	1250
» 3 до 10		440	525	635	765	905	1140	1255	1385	1525	1685	1095	1120	1155	1195	1235
» 10 до 20		390	465	555	655	770	1090	1205	1335	1475	1635	1085	1110	1145	1185	1225
» 20 до 50		365	435	520	620	730	1060	1175	1305	1445	1605	1075	1100	1135	1175	1215
» 50 до 200		345	400	480	575	685	1035	1150	1280	1420	1570	1065	1090	1125	1165	1205
» 200 до 500		320	375	445	530	635	995	1105	1235	1375	1520	1055	1080	1115	1155	1195
» 500 до 1 000		305	355	420	500	605	970	1080	1200	1335	1485	1045	1070	1105	1145	1185
» 1 000 до 3 000		295	345	410	485	575	950	1055	1175	1310	1460	1035	1060	1095	1135	1175
» 3 000 до 10 000		275	330	390	460	555										
» 10 000 и более		265	320	380	450	540										
		260	310	370	440	530										

Appendix 3 (cont'd)

Материал поковки																
19	21		22		20											
	Сталь 15Х--50Х (ГОСТ 4343--61)		Углеродистая качественная сталь 08--85 (ГОСТ 1050--60)		Сталь 33ХС, 38ХС, 40ХС, 18ХГТ, 30ХГТ и 25ХГТ (ЦИТУ/ДИНИЧМ 561--61, ГОСТ 4543--61)											
	Группа сложности															
Вес поковки в кг	7		8		10		11		7		8		10		11	
	Простые	Несложные	Сложные	Особо слож- ные	Простые	Несложные	Сложные	Особо слож- ные	Простые	Несложные	Сложные	Особо слож- ные	Простые	Несложные	Сложные	Особо слож- ные
До 2	395	445	500	585	350	400	450	510	420	470	525	610	420	470	525	610
от 2 до 10	350	395	445	505	310	350	400	450	375	420	470	530	340	380	425	470
» 10 » 25	315	355	400	445	275	310	360	410	340	380	425	435	315	350	390	435
» 25 » 70	290	325	365	410	250	275	325	375	295	325	360	400	295	325	360	400
» 70 » 180	270	300	335	375	235	255	300	345	280	305	335	370	280	305	335	370
» 180 » 320	255	280	310	345	225	240	280	320	265	285	310	340	265	285	310	340
» 320 » 700	245	265	290	320	215	225	260	295	255	270	290	315	255	270	290	315
» 700 » 1 000	235	250	270	295	205	215	240	270	240	255	280	305	240	255	280	305
» 1 000 » 3 000	225	240	260	285	200	210	230	250	210	225	245	270	210	225	245	270
» 3 000 » 4 500	220	235	255	280	195	205	220	240	235	250	270	295	235	250	270	295
» 4 500 » 10 000	215	230	250	275	190	200	215	230	230	245	265	290	230	245	265	290
» 10 000 » 14 000	210	225	245	270	185	195	210	225	225	240	260	285	225	240	260	285
» 14 000 и более	205	220	240	265	183	190	205	220	225	240	260	285	225	240	260	285

### Appendix 3 (cont'd)

[illegible]

### Appendix 3 (cont'd)

[illegible]

Key to appendix: 1 -- weight of casting, kg; 2 -- casting material; 3 -- gray cast iron; 4 -- high-strength cast iron; 5 -- carbon steel; 6 -- complexity group; 7 -- simple; 8 -- uncomplex; 9 -- medium complexity; 10 -- complex; 11 -- highly complex; 12 -- up to; 13 -- from... to; 14 -- alloy structural steel; 15 -- aluminum alloys; 16 -- copper-zinc alloys; 17 -- and more; 18 -- wholesale prices on smith forgings and hot stampings, in rubles per ton; 19 -- weight of forging, kg; 20 -- forging material; 21 -- steel; 22 -- high-quality carbon steel; 23 -- weight of stamping, kg; 24 -- stamping material; \* -- according to wholesale price list 25-01, published in 1966

# Appendix 4

Average Procurement Price  $C_0$  Per Unit of Waste by Weight, in rubles per kg\*

Наименование вида отходов	1	$C_0$
Стружка: 2		
стальная витая . 3 . . . . .		0,0188
стальная мелкая . 4 . . . . .		0,0232
стальная и чугунная для доменных печей . 5 . . . . .		0,0171
стальная легированная . 6 . . . . .		0,050
Алюминиевые сплавы: 7		
в кусках . . . . . 8 . . . . .		0,328
стружка . . . . . 9 . . . . .		0,241
Медь: 10		
в кусках . . . . . 8 . . . . .		0,613
стружка . . . . . 9 . . . . .		0,504
Бронза: 11		
оловянистая . . . . . 12 . . . . .		0,767
свинцовистая . . . . . 13 . . . . .		0,355
Латунь: 14		
в кусках . . . . . 8 . . . . .		0,512
стружка . . . . . 9 . . . . .		0,404
Цинк 15 . . . . .		0,213
16 Смесь двух или более цветных металлов, сплавов		0,184
17 Стружка жаропрочной стали (ЭИ435 или ЭИ437)		2,670
18 Стружка жаропрочная смешанная . . . . .		0,500

\* По прейскурантам оптовых цен 01-08 (1966 г.) и 02-05 (1966 г.)

Key to appendix: 1 -- type of waste; 2 -- chips; 3 -- steel, continuous spiral; 4 -- fine steel; 5 -- steel and cast iron for blast furnaces; 6 -- alloy steel; 7 -- aluminum alloys; 8 -- in pieces; 9 -- chips; 10 -- copper; 11 -- bronze; 12 -- tin; 13 -- copper-lead alloy; 14 -- brass; 15 -- zinc; 16 -- mix of two or more nonferrous metals, alloys; 17 -- heat-resisting steel chips (EI435 or EI437); 18 -- heat-resisting mixed chips; \* -- according to wholesale price lists 01-08 (1966) and 02-05 (1966)

# Appendix 5

Hourly Wage Rates  $C_T$  in Rubles for Machine Building and Metalworking Industry Workers

1 Условия труда и оплаты	2 Группа пред-прият-ий	3 Разряды					
		I	II	III	IV	V	VI
Повременно, холодные работы . 4 . . . . .	1	0,275	0,311	0,355	0,407	0,473	0,550
	2	0,263	0,297	0,33	0,339	0,452	0,526
Сдельно, холодные работы; повременно, горячие и тяжелые работы . 5 . . . . .	1	0,320	0,362	0,413	0,474	0,550	0,640
	2	0,305	0,345	0,395	0,451	0,525	0,610

Appendix 5 (cont'd)

1 Условия труда и оплаты	2 Группа пред-прия-тий	3 Разряды					
		I	II	III	IV	V	VI
Сдельно, горячие и тя- желые работы; повремен- но, особо тяжелые рабо- ты . . . . . 6 . . . . .	1	0,367	0,415	0,478	0,548	0,631	0,734
	2	0,350	0,395	0,451	0,516	0,602	0,700
Сдельно, особо тяже- лые работы . 7 . . . . .	1	0,390	0,441	0,503	0,577	0,671	0,780
	2	0,378	0,427	0,488	0,559	0,650	0,756
Тарифные коэффициен- ты . . . . . 8 . . . . .	—	1,00	1,13	1,29	1,48	1,72	2,00
Примечание. К первой группе предприятий относятся предприя- тия авиационной, автомобильной, инструментальной, оборонной, подшипни- ковой, радиотехнической, станкостроительной, судостроительной, трактор- ной, электротехнической промышленности, транспортного и сельскохозяй- ственного машиностроения, приборостроения, по производству оборудова- ния для горнорудной, металлургической, нефтегазодобывающей, химиче- ской и торфяной промышленности, а также по производству бурового, насосно-компрессорного и холодильного оборудования.							

Key to appendix: 1 -- working conditions and terms of remuneration; 2 -- enterprise group; 3 -- categories; 4 -- hourly wage, cold jobs; 5 -- piece-rate, cold jobs; hourly wage, hot and heavy jobs; 6 -- piece-rate, hot and heavy jobs; hourly wage, extremely heavy jobs; 7 -- piece rate, extremely heavy jobs; 8 -- wage rate factors; note: the first enterprise group in-cludes enterprises in the aircraft, automotive, tool, defense, bearing, radio equipment, machine tool, shipbuilding, tractor, and electrical equipment in-dustries, transport and agricultural machine building, instrument engineer-ing, manufacture of equipment for the mining, metallurgical, petroleum production, chemical and peat industries, as well as production of drilling, pump-compressor and refrigeration equipment

Appendix 6

Average Machine-Factor Values, by Equipment Groups

Группа оборудования 1	2 Краткая техническая характеристика	К <sub>м</sub>
Станки: 3 4 токарно-винторезные	Высота центров в мм: 5	
	(6) до 200	0,95
	201—300	1,27
	301—400	1,56
	401—500	3,00
	501—600	3,46

## Appendix 6 (cont'd)

1 Группа оборудования	2 Краткая техническая характеристика	К <sub>м</sub>
7 токарно-карусельные	Диаметр планшайбы в мм: 8 до 1120 1121—1400 1401—2000 2251—2800 3080—4000	2,68 3,61 4,87 6,4 13,45
9 токарные много- резцовые полуав- томаты	Высота центров в мм: 5 (6) До 150 (10) Свыше 150 (до 200) » 200 (до 250)	1,35 1,78 2,8
токарно-револьвер- ные 11	Диаметр обрабатываемых изде- лий в мм: 12 18—36 37—65 от 66	0,92 1,27 1,51 1,9
вертикально-свер- лильные 14	Обработка изделий в патроне 500 мм 13 Наибольший диаметр сверла в мм: 15 12 13—35 36—75 76—100 Свыше 100	0,48 0,74 1,21 2,25 3,26
горизонтально-рас- точные 16	Диаметр выдвижного шпинде- ля в мм: 17 80 81—110 111—150 150—175 176—200	1,7 3,06 4,42 8,47 13,6
18 круглошлифовальные	Высота центров в мм: 5 До 100 101—200 201—275 276—375 376 и выше	1,52 1,83 2,43 3,2 6,51
19 плоскошлифовальные	Размеры горизонтального стола в мм: 20 До 1000×300 От 1000×300 до 2000×400 » 2000×400 » 2000×800 4000×1150	1,38 1,62 4,3 6,6
22 зубообрабатывающие	Диаметр круглого стола в мм: 400—750 (21) 751—1000 Зубофрезерные с наибольшим (23) диаметром обработки в мм: от 750 до 1250 » 1250 до 1600 Зубодолбежные с наибольшим диаметром обработки изделия в мм: 24 500 от 500 до 1250	2,0 2,7 2,36 3,27 1,68 2,7

## Appendix 6 (cont'd)

1 Группа оборудования	2 Краткая техническая характеристика	К <sub>м</sub>
22зубообрабатывающие	Зубошлифовальные с наибольшим диаметром обрабатываемого изделия в мм: 25 320 700—800 от 800 и выше	2,58 3,6 7,8
	Зубострогальные с наибольшим диаметром обрабатываемого изделия в мм: 26 120 450—600 Свыше 600	1,4 1,91 3,03
горизонтально-фрезерные 28 вертикально-фрезерные 29	Рабочая поверхность стола в мм: 27 1000×250 От 1250×300 до 1600×400 До 1000×250 От 1000×250 до 1250×300 » 1250×300 » 1600×400 » 1600×400 » 2000×800 Свыше 2000×800	1,14 1,52 1,1 1,46 1,76 1,95 5,51
универсально-фрезерные 30	Рабочая поверхность стола в мм: 27 До 1000×250 От 1000×250 до 1250×300 » 1250×300 » 1600×400 » 3000×900 » 4000×1250 » 4000×1250 » 6000×2500 » 8000×2400	1,15 1,2 1,48 5,0 6,3 9,01
продольно-строгальные 31	Наибольший ход ползуна в мм: (33) До 700 От 700 до 900	1,05 1,29
поперечно-строгальные 32	Ход долбления в мм: 35 До 200 От 200 до 320	1,1 1,39
долбежные 34	Максимальное усилие на штоке в т: 37 До 20 от 20 до 40	3,01 5,59 0,1 0,2
горизонтально-протяжные 36	Точила заточные: 38 для сверл 39 для резцов 40 универсальные 41	0,5—1,0 0,4
Молоты пневматические, ковочные 42	Вес падающих частей в кг: 43 До 150 400—750 750—1000 Св. 1500	1,5 5,31 6,05 21,75

Appendix 6 (cont'd)

Группа оборудования 1	Краткая техническая характеристика 2	$K_m$
Прессы механические 44	Максимальное усилие в т: 45 25 25—50 100—160 160—250 400—630 2000—2500	0,53 1,0 2,49 3,47 4,19 17,74
Горизонтально-ковочные машины 46	Максимальное усилие в т: 45 100 100—250 250—630 630—800	2,11 4,39 6,32 9,65
Гильотинные ножницы 47	Толщина разрезаемого листа в мм: 48 До 3 » 6,3 » 10 » 16	0,62 1,1 2,21 2,73
Электроды сопротивления для термообработки: 49 камерные 51	Мощность в квт: 50 До 15 16—30 31—45 46—60 61—75	1,32 2,59 3,81 5,46 6,21
шахтные 52	До 24 25—34	2,13 3,11
Гидравлические прессы для прессовки пластмасс 53	Усилие до: 54 50 51—100 от 100 до 160 » 160 » 250	0,89 1,65 2,29 2,63
Литьевые машины для пластмасс 55	Вес деталей в г: 56 До 100 от 100 до 125 До 5000	1,73 1,82 6,18
Бегуны смешивающие с вертикально-вращающимися катками 57	Диаметр катка и чаши в мм: 58 До 800×1700 От 800×1700 до 900×2400 Свыше 900×2400	2,1 4,19 5,32
Формовочные машины встряхивающие 59	Диаметр встряхивающего цилиндра в мм: 60 До 100 от 100 до 250 » 250 » 330 » 330 » 550	1,22 2,33 4,34 8,95

Key to appendix: 1 -- equipment group; 2 -- brief technical description; 3 -- machine tools; 4 -- screw-cutting lathes; 5 -- swing, mm; 6 -- up to; 7 -- vertical boring and turning mills; 8 -- chuck diameter, mm; 9 -- semiautomatic gang lathes; 10 -- greater than; 11 -- turret lathes;

(Key to Appendix 6 continued from preceding page) 12 -- workpiece diameter; 13 -- turning workpiece in 500 mm chuck; 14 -- vertical drilling machine; 15 -- maximum drill diameter, mm; 16 -- horizontal boring machines; 17 -- diameter of sliding spindle, mm; 18 -- cylindrical grinder; 19 -- surface grinders; 20 -- dimensions of horizontal table, mm; 21 -- diameter of round table, mm; 22 -- gear-machining units; 23 -- gear-milling machines with maximum milling diameter, mm; 24 -- gear-shaping machines with maximum machining diameter, mm; 25 -- gear-grinding machines with maximum workpiece diameter, mm; 26 -- gear-shaving machines, with maximum workpiece diameter, mm; 27 -- table working surface, mm; 28 -- horizontal milling machines; 29 -- vertical milling machines; 30 -- universal milling machines; 31 -- planing machines; 32 -- shaping machines; 33 -- maximum slide stroke, mm; 34 -- slotting machines; 35 -- slotting stroke, mm; 36 -- horizontal pull-broaching machines; 37 -- maximum force on rod, tons; 38 -- grinding wheels; 39 -- for drills; 40 -- for cutting tools; 41 -- general-purpose; 42 -- pneumatic forging hammers; 43 -- weight of falling parts, kg; 44 -- power presses; 45 -- maximum force, tons; 46 -- hot-forging machines; 47 -- squaring shears; 48 -- thickness of cut sheet, mm; 49 -- resistance furnaces for heat treatment; 50 -- output, kw; 51 -- box; 52 -- shaft; 53 -- hydraulic presses for pressing plastics; 54 -- force to; 55 -- casting machines for plastics; 56 -- weight of castings, g; 57 -- mixing machines with vertically-rotating rollers; 58 -- roller and mill diameter, cm; 59 -- jolt-squeezer molding machines; 60 -- diameter of jolt-squeezing cylinder, mm

## Appendix 7

### Average Cost Per Hour of Cutting Tool Operation

Наименование инструмента	1	Средний размер в мм 2	Стоимость в коп. 3
Резцы: 4			
проходные быстрорежущие 5		15×25×150	3,3
твердосплавные 6		15×25×150	5,0
фасонные призматические 7		120×90	6,2
круглые фасонные 8		Ø 75	4,4
Фрезы: 9			
дисковые цельные 10		Ø 130×25	11,2
дисковые сборные 11		Ø 175×25	12,3
червячные цельные 12		M-3	28,5
червячные сборные 13		M-6	28,5
резьбовые 14		Ø 75×40	15,2
концевые 15		Ø 30	9,3
шлицевые 16		Ø 40—50	45,4
шпоночные 17		B=10—12	23,0
Фрезы-пилы 18		Ø 175×4	8,2
Протяжки круглые 19		Ø 30—35	30,5
Сверла спиральные с цилиндрическим хвостом 20		Ø 10	7,8
То же с конусным хвостом 21		Ø 20	8,0
То же 22		Ø > 20	10,3
Зенкеры быстрорежущие 23		Ø 20	4,6
То же 24		Ø > 20	7,2
Зенкеры твердосплавные 25		Ø > 35	9,0
Развертки быстрорежущие 26		Ø 20	7,8
Развертки быстрорежущие 27		Ø > 20	12,8
Цековки твердосплавные 28		Ø 50	10,6
Метчики быстрорежущие 29		Ø 20	8,0
То же 30		Ø > 20	13,0
Плашки круглые к резьбонарезным головкам 31		Патрон 1" (30)	15,0
Долбяки 32		черновая обработка (310)	35,0

Key to Appendix 7 on preceding page: 1 -- tool; 2 -- average dimensions, mm; 3 -- cost, kopecks; 4 -- lathe tools; 5 -- high-speed; 6 -- hard-alloy; 7 -- knife-edge forming tools; 8 -- round forming tools; 9 -- milling cutters; 10 -- face-and-side solid-type cutters; 11 -- face-and-side inserted-blade cutters; 12 -- inserted-blade hob cutters; 14 -- thread cutters; 15 -- shank cutters; 16 -- slot cutters; 17 -- spline cutters; 18 -- milling cutter-saws; 19 -- round pull broaches; 20 -- straight-shank twist drills; 21 -- tapered-shank twist drills; 22 -- same; 23 -- high-speed counterbores; 24 -- hard-alloy counterbores; 25 -- high-speed reamers; 26 -- hard alloy spotfacers; 27 -- high-speed taps; 28 -- round threading dies; 29 -- gear-shaper cutters; 30 -- chuck; 31 -- rough machining

## Appendix 8

Values of  $k_{emf}$  Factor

Коэффициент использования электродвигателя по мощности 1	Коэффициент использования электродвигателя по времени 2											
	0,30	0,35	0,40	0,45	0,50	0,55	0,60	0,65	0,70	0,75	0,80	0,85
0,35	0,12	0,14	0,15	0,17	0,19	0,21	0,23	0,25	0,27	0,29	0,31	0,33
0,40	0,13	0,15	0,18	0,20	0,22	0,24	0,27	0,29	0,31	0,33	0,36	0,38
0,45	0,15	0,17	0,20	0,22	0,25	0,27	0,30	0,32	0,35	0,37	0,40	0,42
0,50	0,17	0,19	0,22	0,25	0,28	0,31	0,33	0,36	0,39	0,42	0,44	0,47

Коэффициент использования электродвигателя по мощности 1	2 Коэффициент использования электродвигателя по времени											
	0,30	0,35	0,40	0,45	0,50	0,55	0,60	0,65	0,70	0,75	0,80	0,85
0,55	0,18	0,21	0,24	0,27	0,31	0,33	0,36	0,40	0,43	0,46	0,49	0,52
0,60	0,20	0,23	0,27	0,30	0,33	0,37	0,40	0,43	0,47	0,50	0,53	0,57
0,65	0,22	0,25	0,29	0,33	0,36	0,40	0,43	0,47	0,51	0,54	0,58	0,61
0,70	0,23	0,27	0,31	0,35	0,39	0,43	0,47	0,51	0,54	0,58	0,62	0,66
0,75	0,25	0,29	0,33	0,37	0,42	0,46	0,50	0,54	0,58	0,62	0,67	0,71
0,80	0,27	0,31	0,35	0,40	0,44	0,49	0,53	0,58	0,62	0,67	0,71	0,76

Key to appendix: 1 -- electric motor utilization factor, output; 2 -- electric motor utilization factor, time

## Hourly Outlays on Industrial Process Electric Power

Наименование оборудования 1	$E_{q_1}$ в коп. 2
<i>Металлорежущее оборудование 3</i>	
Электродвигатели металлорежущих станков 4 . . . . .	0,34N <sub>y</sub>
Электродвигатели автоматов, полуавтоматов, револьверных, резьбофрезерных, зубофрезерных, протяжных, а также крупных станков: токарных, фрезерных, карусельных, расточных и т. п. 5 . . . . .	0,42N <sub>y</sub>
<i>Кузнечно-прессовое оборудование 6</i>	
Молоты и ковочные машины 7 . . . . .	0,68N <sub>y</sub>
Прочее оборудование кузнечно-прессовых цехов 8 . .	0,42N <sub>y</sub>
<i>Литейное оборудование 9</i>	
Все оборудование, кроме элеваторов и транспортеров 10	0,68N <sub>y</sub>
Элеваторы и транспортеры . . . 11 . . . . .	0,85N <sub>y</sub>
<i>Подъемно-транспортное оборудование 12</i>	
Краны, тельферы ПВ 25% . . . 13 . . . . .	0,17N <sub>y</sub>
ПВ 40% . . . . .	0,34N <sub>y</sub>
(ПВ% = $\frac{\text{Время работы механизма в течение цикла}}{\text{Полное время цикла}} \times 100$ ) 14	
<i>Электросварочное, печное оборудование, установки ТВЧ 16</i>	
Электродвигатели сопротивления, дуговые электропечи, электропечи-ванны, сушильные шкафы, нагревательные приборы, индукционные печи низкой частоты . 17 . . .	1,36N <sub>y</sub>
Сварочные машины шовные, трансформаторы и преобразователи сварочные . . . . 18 . . . . .	0,59N <sub>y</sub>
Точечные и стыковые сварочные машины 19 . . . . .	1,02N <sub>y</sub>
Высокочастотные установки . . . . . 20 . . . . .	1,36N <sub>y</sub>
Сварочные трансформаторы и преобразователи, работающие в паре с автоматами и полуавтоматами . . . 21 . .	0,85N <sub>y</sub>

Key to appendix: 1 -- equipment; 2 -- in kopecks; 3 -- metal-cutting equipment; 4 -- metal-cutting machine tool electric motors; 5 -- electric motors of automated and semiautomated machine tools, turret lathes, thread-milling machines, gear-milling machines, pull-broaching machines as well as large machine tools: lathes, milling machines, vertical turning and boring mills, boring machines, etc; 6 -- press forging equipment; 7 -- hammers and forging machines; 8 -- other press forging equipment; 9 -- foundry equipment; 10 -- all equipment other than hoist and conveyor equipment; 11 -- hoist and conveyor equipment; 12 -- materials handling equipment; 13 -- cranes, telfers; 14 -- equipment operating time during cycle; 15 -- total cycle time; 16 -- electric welding, furnace equipment, high-frequency current equipment; 17 -- resistance furnaces, arc furnaces; electrolytic furnaces, drying stoves, heating devices, low-frequency induction furnaces; 18 -- seam welding machines, welding transformers and converters; 19 -- spot and butt welding machines; 20 -- high-frequency equipment; 21 -- welding transformers and converters coupled with automated and semiautomated units

## Formulas for Calculating Item Hourly Outlays R

Наименование оборудования	1	$R_q$ в коп.	2
<i>Металлорежущее</i> 3			
Универсальные и специальные легкие и средние станки весом до 10 т, работающие не с абразивным инструментом: 4			
5	токарные, сверлильные, фрезерные и т. д.	$0,54R_M + 0,4R_3$	
6	автоматы и полуавтоматы . . . . .	$0,73R_M + 0,4R_3$	
7	резьбофрезерные, зубофрезерные и протяжные . . . . .	$0,69R_M + 0,4R_3$	
	То же, работающие абразивным инструментом 8 . . . . .	$0,58R_M + 0,7R_3$	
Универсальные и специальные крупные и тяжелые станки весом 10—100 т, работающие с неабразивным инструментом: 9			
5	токарные, сверлильные, фрезерные и т. д.	$0,65R_M + 0,4R_3$	
6	автоматы и полуавтоматы . . . . .	$0,83R_M + 0,4R_3$	
7	резьбофрезерные, зубофрезерные и протяжные . . . . .	$0,79R_M + 0,4R_3$	
	То же, работающие с абразивным инструментом 10 . . . . .	$0,7R_M + 0,7R_3$	
	Особо тяжелые и уникальные станки весом свыше 100 т 11 . . . . .	$0,76R_M + 0,5R_3$	
	Агрегатные станки 12 . . . . .	$0,68R_M + 0,4R_3$	
<i>Кузнечно-прессовое</i> 13			
14	Молоты с весом падающих частей до 150 кг, ковочные машины усилием до 1000 т	$R_M + 0,78R_3$	
15	Молоты с весом падающих частей свыше 150 кг, ковочные машины усилием свыше 1000 т . . . . .	$1,31R_M + 0,82R_3$	
16	Кузнечно-прессовые автоматы . . . . .	$0,75R_M + 0,41R_3$	
17	Прессы разные:		
18	усилием до 300 т и фрикционные свыше 300 т . . . . .	$0,82R_M + 0,41R_3$	
19	усилием 300—600 т . . . . .	$R_M + 0,41R_3$	
	свыше 600 т 20 . . . . .	$1,26R_M + 0,41R_3$	
	Прессы гидравлические: 21		
	усилием до 1000 т . . . . . 22 . . . . .	$0,95R_M + 0,41R_3$	
	свыше 1000 т . . . . . 23 . . . . .	$1,25R_M + 0,41R_3$	
	Гибочные машины 24 . . . . .	$0,98R_M + 0,41R_3$	
	Ножницы разные . . . . . 25 . . . . .	$0,9R_M + 0,41R_3$	
<i>Литейное землеприготовительное</i> 26			
	Бегуны, транспортеры для горячей формочной смеси . . . . . 27 . . . . .	$3,47R_M + 0,78R_3$	
	Рыхлители и сита . . . . . 28 . . . . .	$2,62R_M + 0,78R_3$	

## Appendix 10 (cont'd)

1	Наименование оборудования	$R_q$ в коп.	2
	Транспортеры свежей формовочной смеси, подвальные элеваторы, напольные транспортеры . 29 . . . . .	$1,87R_m + 0,78R_s$	
	Машины для регенерации формовочных и стержневых смесей . 30 . . . . .	$1,52R_m + 0,78R_s$	
	Выбивное 31		
	Выбивные решетки : 32 . . . . .	$2,62 R_m + 0,78R_s$	
	Оборудование для гидровывивки стержней, гидродомкраты . . . . . 33 . 34 . . . . .	$1,5R_m + 0,78R_s$ $1,5R_m + 0,78R_s$	
	Прочие выбивные устройства . . . . .		
	Очистное 35		
	Очистные галтовочные барабаны 36 . . . . .	$3,38R_m + 0,78R_s$	
	Дробебетонные, дробеструйные камеры и аппараты . . . . . 37 . . . . .	$3R_m + 0,78R_s$	
	Формовочное и стержневое 38		
	Формовочные машины грузоподъемностью до 900 кг . . 39 . . . . .	$2,22R_m$	
	То же, от 900 до 5000 кг 40 . . . . .	$1,36R_m$	
	Стержневые машины 41 . . . . .	$2,04R_m$	
	Пескометы, машины для пескометной набивки форм . . . . . 42 . . . . .	$1,5R_m$	
	Оборудование для заливки 43		
	Машины для литья под давлением, кокильные и центробежные машины, оборудование для литья в оболочковые формы, оборудование для литья по выплавляемым моделям . . . . . 44 . . . . .	$1,71R_m + 0,78R_s$ $2R_m + 0,95R_s$	
	Литейные конвейеры 45 . . . . .	$110,85R_m$	
	Вагранки . . . . . 46 . . . . .		
	Электросварочное 47		
	Сварочные трансформаторы, преобразователи, автоматы и полуавтоматы . . . . . 48 . . . . .	$0,5R_s$	
	Сварочные машины для точечной, шовной и стыковой сварки . . . . . 49 . . . . .	$0,63R_s$	
50	Печное оборудование и установки т. в. ч.		
	Кузнечные и термические печи на жидком и газообразном топливе . 51 . . . . .	$3,81R_m$	
	Сушильные печи на жидком и газообразном топливе . . . . . 52 . . . . .	$1,59R_m$	
	Электropечи сопротивления . . . . . 53 . . . . .	$0,65R_m + 0,52R_s$	
	Дуговые электropечи . . . . . 54 . . . . .	$0,86R_m + 0,72R_s$	

Appendix 10 (cont'd)

Наименование оборудования	1	$R_q$ в коп.	2
Электропечи-ванны .55. . . . .		$0,66R_M + 0,53R_3$	
Установки т. в. ч.: 56			
с машинным генератором 57. . . . .		$0,65R_3$	
с ламповым генератором .58. . . . .		$0,76R_3$	
Подъемно-транспортное 59			
Краны, однорельсовые тележки и электри- ческие тали: 60			
цехи холодной обработки металлов 61. .		$0,86R_M + 0,54R_3$	
цехи горячей обработки металлов 62. .		$0,87R_M + 0,94R_3$	

Key to appendix: 1 -- equipment; 2 -- in kopecks; 3 -- metal-cutting; 4 -- universal and special light and medium machine tools weighing up to 10 tons, not operating with abrasive points; 5 -- lathes, drilling machines, milling machines, etc; 6 -- automatic and semiautomatic units; 7 -- thread-milling, gear-milling and pull-broaching machines; 8 -- same, operating with mounted abrasive points; 9 -- universal and special large and heavy machine tools weighing from 10 to 100 tons, operating with nonabrasive tools; 10 -- same, operating with abrasive points; 11 -- particularly heavy and custom machine tools weighing in excess of 100 tons; 12 -- gang tools; 13 -- press forging; 14 -- hammers with dropping parts weighing up to 150 kg, forging machines with force up to 1,000 tons; 15 -- hammers with dropping parts weighing more than 150 kg, forging machines with force in excess of 1,000 tons; 16 -- automatic press forging equipment; 17 -- various presses; 18 -- up to 300 tons, and friction presses above 300 tons; 19 -- 300-600 tons; 20 -- above 600 tons; 21 -- hydraulic presses; 22 -- to 1,000 tons; 23 -- above 1,000 tons; 24 -- bending machines; 25 -- various shears; 26 -- foundry, molding sand preparation; 27 -- mixing machines, conveyers for hot molding sand; 28 -- looseners and sifting screens; 29 -- fresh molding sand conveyers, overhead hoists, floor conveyers; 30 -- machines for regenerating molding and core sand; 31 -- shakeout; 32 -- shakeout grids; 33 -- hydraulic core-knockout equipment, hydraulic jacks; 34 -- other shakeout devices; 35 -- cleaning; 36 -- tumbling barrels; 37 -- shot-blasting chambers and equipment; 38 -- molding and core; 39 -- molding machines, capacity to 900 kg; 40 -- same, from 900 to 5,000 kg; 41 -- core machines; 42 -- sandslingers, machines for sandslinging mold packing; 43 -- casting equipment; 44 -- pressure casting machines, chill molding and centrifugal casting machines, equipment for shell-mold casting, equipment for investment casting; 45 -- foundry conveyers; 46 -- cupola furnaces; 47 -- electric welding; 48 -- welding transformers, converters, automatic and semiautomatic equipment; 49 -- welding machines for spot, seam and butt welding; 50 -- furnace equipment and high-frequency current installations; 51 -- liquid and gas-fuel forge and heat-treating furnaces; 52 -- liquid and gas-fueled drying ovens; 53 -- resistance furnaces; 54 -- arc furnaces; 55 -- electrolytic furnaces; 56 -- high-frequency current equipment; 57 -- with mechanical oscillator; 58 -- with tube oscillator; 59 -- materials handling; 60 -- cranes, monorail cars and electric block and tackle; 61 -- cold metalworking shops; 62 -- hot metalworking shops

# Appendix 11

## Standard Annual Depreciation Allowances for Certain Types of Process Equipment

1	2	3	
		4	5
Вид технологического оборудования	Общая норма в а, %	на капитальные ремонты	на полное восстановление
<b>1. Металлорежущие станки 6</b>			
7 Универсальные и специализированные легкие и средние станки весом до 10 т, работающие абразивным инструментом	16,4* 12,0** 10,7***	9,7 7,2 6,5	6,7 4,8 4,2
8 Универсальные и специализированные легкие и средние станки весом до 10 т, работающие неабразивным инструментом . . . . .	14,9* 12,2** 10,9***	9,3 7,6 6,9	5,6 4,6 4,0
9 Универсальные и специализированные крупные и тяжелые станки весом от 10 до 100 т, работающие абразивным инструментом . . . . .	12,1* 10,0** 8,8***	7,4 6,2 5,5	4,7 3,8 3,3
10 Универсальные и специализированные крупные и тяжелые станки весом от 10 до 100 т, работающие неабразивным инструментом . . . . .	14,2* 11,9** 10,2***	10,0 8,4 7,3	4,2 3,5 2,9
Особо тяжелые и уникальные станки весом свыше 100 т . 11 . . . . .	5,0** 4,6***	2,3 2,2	2,7 2,4
Агрегатные и специальные станки 12	13,4* 10,3**	5,1 4,0	8,3 6,3
Автоматические линии . 13 . . . . .	12,2*	3,9	8,3
<div>* Массовое и крупносерийное производство. ** Серийное производство. *** Мелкосерийное и индивидуальное производство.</div>			
<b>II. Литейные машины и оборудование 14</b> (массовое и серийное производство)			
15 Землеприготовительное оборудование	23,5	13,5	10,0
16 Формовочное и стержневое оборудование . . . . .	18,0	8,0	10,0
17 Выбивное оборудование . . . . .	49,5	16,2	33,3
18 Очистное оборудование . . . . .	19,5	7,0	12,5
19 Оборудование для литья в металлические формы . . . . .	9,9	3,2	6,7
20 Вагранки . . . . .	22,0	15,0	7,0
21	Примечание. В мелкосерийном производстве общую норму следует умножать на коэффициент 0,6.		

PAGES 158 & 159  
ARE  
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ORIGINAL  
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Key to Appendix 11 on preceding pages: 1 -- type of process equipment; 2 -- general standard figure in a, %; 3 -- including; 4 -- for major repairs; 5 -- for full replacement; 6 -- metal-cutting machine tools; 7 -- universal and specialized light and medium machine tools weighing up to 10 tons, operating with mounted abrasive points; 8 -- universal and specialized light and medium machine tools weighing up to 10 tons, operating with nonabrasive tools; 9 -- universal and specialized large and heavy machine tools weighing from 10 to 100 tons, operating with mounted abrasive points; 10 -- universal and specialized large and heavy machine tools weighing from 10 to 100 tons, operating with nonabrasive tools; 11 -- particularly heavy and custom machine tools weighing in excess of 100 tons; 12 -- special machine tools and gang tools; 13 -- automated lines; \* -- mass and large-series production; \*\* -- series production; \*\*\* -- small-series and single-unit production; 14 -- casting machines and equipment (mass and series production); 15 -- sand preparation equipment; 16 -- molding and core equipment; 17 -- shakeout equipment; 18 -- cleaning equipment; 19 -- equipment for casting in metal molds; 20 -- cupola furnaces; 21 -- note: in small-series production the general standard figure should be multiplied by a factor of 0.6; 22 -- press forging equipment; 23 -- light presses for metalworking, presses for working other materials (power and hydraulic presses, automatic equipment, shears and straightening-bending machines, etc); 24 -- heavy presses, weighing more than 30 tons; 25 -- hammers, forging machines; 26 -- electric motors and diesel generators; 27 -- electric motors; 28 -- up to 100 kilowatts; 29 -- greater than 100 kilowatts; 30 -- diesel generators; 31 -- up to 50 500 rpm; 32 -- 500 rpm and higher; 33 -- compressor equipment; 34 -- general-purpose piston compressors, pressure to 8 atm, output up to 20 m<sup>3</sup>/min; 35 -- general-purpose piston compressors, pressure up to 8 atm, output greater than 20 m<sup>3</sup>/min; 36 -- special (air) compressors, pressure greater than 8 atm, gas compressors, rotary compressors; 37 -- gas blowers, blast blowers, turbocompressors; 38 -- mobile compressors, mobile compressor stations; 39 -- vacuum pumps; 40 -- note: standard figures in sections I-V were determined on the basis of two-shift equipment operation. For three-shift operations a factor of 1.2 is employed, with one-shift operations, 0.8; 41 -- ventilation equipment; 42 -- main ventilation systems; 43 -- partial ventilation blowers; 44 -- air collectors; 45 -- materials handling equipment; 46 -- gantry cranes, capacity; 47 -- up to 15 tons; 48 -- greater than 15 tons; 49 -- traveling cranes; 50 -- cantilever cranes; 51 -- lift trucks, hydraulic lifts, electric forklifts; 52 -- power loaders; 53 -- stackers; 54 -- scraper and plate conveyers; 55 -- belt conveyers; 56 -- transportable; 57 -- disassembling link; 58 -- screw and bucket; 59 -- power winches; 60 -- note: for materials handling equipment employed at industrial enterprises, the general standard depreciation allowance is multiplied by a factor of 0.6; 61 -- welding and gas-cutting equipment; 62 -- transportable welding equipment; 63 -- welding transformers; 64 -- mobile; 65 -- stationary; 66 -- heat-treatment furnaces; 67 -- annealing furnaces, heating furnaces, crucible furnaces, gas furnaces, etc; 68 -- communications equipment; 69 -- lead-in, line and other telephone equipment; 70 -- dispatcher communications intermediate point equipment; 71 -- telegraphy and phototelegraphy equipment, relays and instruments (two-shift operations); 72 -- telephone switchboards

(Key to Appendix 11, continued) and dial telephones; 73 -- television equipment; 74 -- measuring and control instruments and devices; 75 -- centralized dispatch and traffic control operations; 76 -- dispatcher and control monitoring devices; 77 -- monitoring-measuring and test equipment; 78 -- laboratory equipment and apparatus; 79 -- calculators and computers; 80 -- other instruments and devices

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# SYMBOLS APPEARING IN TEXT\*

- $S$  — machinery production cost in rub/unit;
- $S_{azp}$  — ( $S_{un}$ ) cost of producing a unit or assembly in rub/unit;
- $S_{\partial}$  — cost of producing a part, in rubles per unit;
- $S_{uex}$  — shop production cost, in rubles per unit;
- $S_{3as}$  — ( $S_{pl}$ ) plant production cost in rubles per unit;
- $S_{cp}$  — average branch production cost, in rubles per unit;
- $S_{yG}$  — specific cost of production in rubles per ton, rubles per kg;
- $S_{yN}$  — specific production cost in rubles per kw, rubles per hp;
- $S_{np}$  — maximum production cost, rubles per unit;
- $S_{\partial K}$  — ( $S_{ek}$ ) specific operating costs in rubles per unit of productivity;
- $S_o$  — relative production cost, factor;
- $\varphi$  — planned profit factor;
- $p$  — machinery production profitability;
- $P_p$  — profit, rubles per unit;
- $C$  — machinery wholesale-release price, rubles per unit;
- $C_{azp}$  — wholesale-release price of unit or assembly, rubles per unit;
- $C_{\partial}$  — wholesale-release price of part, rubles per unit;
- $C_{azp_n}$  — wholesale-release price of unit or assembly obtained by cooperative manufacture, rubles per unit;
- $C_{\partial_n}$  — wholesale-release price of parts obtained by cooperative manufacture, rubles per unit;
- $C_{n\phi}$  — ( $C_{sm}$ ) wholesale-release price of purchased item or semimanufacture, rubles per unit;
- $C_y$  — specific capital investment, rubles per unit of productivity;
- $C_{np}$  — maximum wholesale-release price, rubles per unit;
- $W$  — machinery productivity in units of productivity per year;

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\* Subscripts H(n) and C (o) appearing in the text signify respectively a parameter applying to a newly-designed machinery item and to a base machinery item selected as object for comparative analysis.

- $E_n$  — ( $E_s$ ) branch standard economic effectiveness factor, 1/year;  
 $V$  — average productive assets value, rubles;  
 $G$  — calculated machinery weight, in kg, t;  
 $G_u$  — ( $G_n$ ) item net weight, in kg/unit, t/unit;  
 $G_p$  — item consumption of material, in kg/unit, t/unit;  
 $N$  — machine motor output, in kw, hp;  
 $M$  — expenditures on materials, semimanufactures and purchased items, rubles per unit;  
 $M_1$  — outlays on basic materials, rubles per unit;  
 $m_u$  — ( $m_u$ ) standard consumption of basic material of a given type per unit of product, in kg/unit, t/unit, m/unit;  
 $m_y$  — expenditure of materials per unit of machinery weight, in kg/kg, t/t;  
 $m_o$  — percentage share of outlays on materials, semimanufactures and purchased items in cost of production;  
 $k_p$  — factor figuring the correlation between net weight and consumption of materials;  
 $m_{or}$  — standard quantity of waste sold per unit of output, in kg/unit, t/unit, m/unit;  
 $k_r$  — factor covering transport-initial processing costs;  
 $c_M$  — average cost of materials, rub/kg, rubles/t;  
 $c$  — wholesale-release price per unit of basic material, in rub/kg, rub/t, rub/m;  
 $c_{or}$  — wholesale-release price per unit of waste, in rub/kg, rub/t, rub/m;  
 $L$  — basic wages of production workers, rubles per unit;  
 $c_r$  — wage rate, rubles per norm-hour;  
 $c_{rc}$  — average wage rate, rubles per norm-hour;  
 $l$  — rate per operation, rubles per unit;  
 $T, T_{обш}$  — ( $T_{tot}$ ) total norm-set labor requirements of manufacture, in norm-hours per unit;  
 $T_{azp}$  — ( $T_{un}$ ) normed labor requirements for producing a unit or assembly, in norm-hours per unit;  
 $T_0$  — normed labor requirements for producing a part, in norm-hours per unit;  
 $t_{y0}$  — labor requirements per unit of machinery weight in norm-hours per kg, norm-hours per ton;  
 $t_{um}$  — unit time norm per operation, in minutes per unit;  
 $n_u$  — ( $n_{hr}$ ) hourly output norm, in units per hour;  
 $\alpha$  — percentage of supplementary wages and social insurance contributions;  
 $K_1$  — shop indirect expenditures as a percentage of basic wages of production workers (or of total basic wages of production workers and estimated rates);  
 $K_2$  — general plant indirect expenditures as a percentage of basic wages of production workers (or of total basic wages of production workers and estimated rates);  
 $K_3$  — nonproduction expenditures as a percentage of plant production cost;  
 $h_{003}$  — expenditures per machine-hour of base machine tool operation, in rubles per hour;  
 $V_{cM}$  — estimated rate, in rubles per unit;  
 $I$  — expenditures on operation and maintenance of tools and dies, in rubles per unit;

$P$  — expenditures on operation and maintenance of accessory devices, rub/unit;  
 $E$  — expenditures on process electricity, rubles per unit;  
 $R$  — expenditures on minor repairs, rubles per unit;  
 $a'$  — annual standard depreciation allowance to full replacement of fixed assets;  
 $a''$  — annual standard depreciation allowance to major overhaul;  
 $A$  — depreciation allowance on equipment, rubles per unit;  
 $A_{n.a}$  — ( $A_{ar}$ ) depreciation allowance on production areas, rubles per unit;  
 $F_{эф}$  — effective equipment operation time fund, hours per year;  
 $\mu$  — factor taking into account expenditures on general assembly;  
 $N_{год}$  — ( $N_{year}$ ) production scale, units per year, thousand units per year; ( $N_{yr}$ )  
 $\delta$  — production run factor;  
 $V_r$  — variable (proportional) expenditures;  
 $c_n$  — fixed-constant expenditures;  
 $y$  — dependent parameter;  
 $x_i$  — parameter-argument;  
 $n$  — number of parameters considered;  
 $a, b$  — constant correlation equation factors;  
 $\beta$  — correlation equation factors in standardized scale;  
 $r$  — correlation factor;  
 $\sigma$  — root-mean-square deviation;

$k_B$  --  $k_b$

$n_r$  --  $n_g$

$k_{yH}$  --  $k_{st}$

$k_{\partial i}$  --  $k_{li}$

$I_{ш}$  --  $I_d$

#### Subscripts:

$H$  --  $n$

$C$  --  $o$

$шT$  --  $un$

$эф$  --  $ef$

$маш$  --  $mach$

$эл$  --  $el$

$сл$  --  $co$

$э$  --  $e$

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3024

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